AN EVALUATION OF FUEL CONVERSION TREATMENTS IN

INTERIOR ALASKA

By

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AN EVALUATION OF FUELS CONVERSION TREATMENTS IN

INTERIOR ALASKA

A

THESIS

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Abstract

The study site was a permafrost-free upland site with an east-northeast aspect, west/northwest of Fairbanks at mile 10 on the Cache Creek road in a mixed hardwood/spruce stand of *Betula neoalaskana* Sarg., *Populus tremuloides* Michx., *Populus balsamifera* L., *Picea glauca* (Moench) Voss, and *Picea mariana* (Mill.) BSP. In treatments designed to encourage hardwood growth, four different methods were used for removing vegetation (shearblading, masticating head, drum-crusher, and chainsaw thinning), resulting material was then left in place, burned, or chunked and removed. Treatments were evaluated using man/machine hour and dollar cost data and Permanent Sample Plot (PSP) data. PSPs were installed within six different fuels conversion treatments and a control for monitoring purposes. A pilot study revealed that debris pile burning changed soil color (more red) and soil water repellency properties. All treatments that had one full growing season showed hardwood regeneration. Shearblading and leaving material on site was the least labor-intensive treatment and least costly. Burning windrows was the least labor-intensive and least costly method of removing material from the site.

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Chapter 1 Introduction

Fire suppression during the last century has changed the character of North America's forests. Putting fires out has led to a buildup of fuels that causes fires that escape initial suppression efforts and become large and catastrophic. The increase in forest fuel is especially important in the area termed the wildland-urban interface. Here the increased potential for loss of timber resources is not the primary concern. Rather, the concern is loss of homes, personal property, and even lives. Historically, less fire suppression has been conducted in Alaska than in Canada or the contiguous United States. Nonetheless, wildfire poses a threat to personal and community property in Alaska's wildland-urban interface.

The Boreal Forest is a fire dependent ecosystem. In this forest, the fire regime is characterized by crown fires and severe ground fires (Kilgore and Heinselman 1990). The impact of fire on Alaska's landscape was especially evident in 2004, when a historical record 6.6 million acres burned; this was followed in 2005 by 4.5 million additional acres as of September.[1] Much of this acreage was away from populated areas; therefore fires were allowed to burn in accordance with the Alaska Interagency Wildland Fire Management Plan (AIWFMP) prepared by the Alaska Interagency Wildland Fire Coordinating Group (AIWFCG 1998). However, a real danger of property loss in the fire dominated landscape of Alaska does exist. A dramatic example of what can happen in Alaska is the 1996 Big Lake fire, north of Anchorage, that

[1] Personal communication. September 22, 2005. Sue Christensen. Ft. Wainwright, AK: Alaska Fire Service, Alaska Interagency Coordination Center.

destroyed 344 structures in the eight days it took to contain the fire (Grissom and others 2000; Jewkes 1999). Each year there is the same potential for fires to cause similar damage to property. For example, Fairbanks residents experienced a near disaster in 2004 when the 538,000-acre Boundary fire burned north of town.[2]

On a national scale, the fuels problem has not escaped the attention of politicians. The United States federal government only recently realized that it is necessary to return forests to a state that is less conducive to losses from wildfire, disease, and insects. Rains and Hubbard (2002) stated that the National Fire Plan began in August of 2000 and originated from a special report to the President from the Secretaries of Agriculture and the Interior that identified four key points:

1. "Continue to make all necessary firefighting resources available;
2. "Restore landscapes and rebuild communities;
3. "Invest in projects to reduce fire risk;" and
4. "Work directly with communities" (Glickman and Babbit 2000).

Under point 3 the report called for the expansion of both acres treated and funding for projects (Glickman and Babbit 2000). One source of funding, the Healthy Forests Restoration Act of 2003, calls for 50% of its funding to be used to protect homes in the wildland-urban interface from wildfire. The State of Alaska is eligible to receive home protection funds under this act; Section 108 Authorization of Appropriations of

[2] Personal communication. September 22, 2005. Sue Christensen. Ft. Wainwright, AK: Alaska Fire Service, Alaska Interagency Coordination Center.

the Act permits grants to "States, local governments, Indian tribes, and other eligible recipients" (United States Senate and House of Representatives 2003).

Fuels treatments in the wildland urban interface are not new; they have been around for many years (Martinson and Omi 2003). What is new is the unprecedented funding support from the United States federal government for fuels management. Land managers in areas without a history of fuels reduction projects are now faced with a challenging task: They are receiving unprecedented sums of money slated for fuels treatments from the National Fire Plan and Healthy Forests Act but have little information that addresses options for fuels treatments and the associated costs and benefits. This lack of information leads to questions concerning how to responsibly spend public funds for fuels reduction. Silvicultural knowledge must be utilized, but fire protection rather than timber production must be the basis for evaluating what treatments are appropriate for any particular stand. For example, instead of fiber production, success in a stand-level treatment could be defined as a change in the species composition or overall structure to a condition that is less prone to catastrophic wildfire.

Fuels conversion treatment refers to any modification of the combustible organic materials on a given site with the intent to change the vegetation type. The plural use of the term fuels refers to the multiple sources of fuel for wildfire within a given stand of trees including materials such as duff, grass, downed woody debris, and standing trees of various species.

For Alaskan forest stands that are capable of supporting hardwood tree species, conversion from spruce to an earlier successional state (hardwoods) that is less prone to catastrophic wildfire is often appropriate. Thus, an evaluation of different approaches to attain cover type change is necessary in Alaska's Tanana Valley that includes most of southeastern interior Alaska. Results from this study should be applicable elsewhere, but most specifically to interior Alaska and especially the Fairbanks area of the Tanana Valley.

The goal of this thesis is to assess various stand-level fuels conversion treatments in the Fairbanks area. Information gained through this study will be utilized to identify the best approaches for fuels treatments on upland sites capable of supporting the more fire-resistant hardwood vegetation.

Specific study objectives (to be used as a basis for making that determination) include:

1. Determine current fuels reduction approaches in interior Alaska and obtain what information exists with respect to costs and treatment effects by speaking with fire and forestry professionals involved in fuels management.
2. Test fuels treatments that are likely to be economically feasible and install Permanent Sample Plots (PSPs) for long-term monitoring of conversion treatments.
3. Quantify differences in regeneration between treatments after one growing season.
4. Evaluate treatments for cost effectiveness based on man/machine hours.

The target audiences for the information generated by this study are managers charged with the implementation of fuels treatments and other interested parties such as property owners, taxpayers, and policy-makers.

Chapter 2 Literature Review

Wildland fire behavior depends on fuel, weather (air mass), and topography (Countryman 1972). Of these three factors, fuel is the only one that can be manipulated by humans (Weatherspoon and Skinner 1995). Fuels management, part of fire management, is designed to modify vegetation to reduce the likelihood of fires and to stop or reduce the spread of fires (Martell 2001).

Martell (2001) assembled the following useful definitions:

- Fire Regime: "five basic elements: (1) fire intensity, (2) the season during which burning takes place, (3) fire size or extent, (4) fire type, and (5) fire frequency" (Whalen 1995).
- Fire Management: "activities concerned with the protection of people, property, and forest areas from wildfire and the use of prescribed burning for the attainment of forest management and other land use objectives, all conducted in a manner that considers environmental, social, and economic criteria" (Merrill and Alexander 1987).

A discussion of fire in Alaskan spruce and hardwoods, studies of fire behavior in fuels treatments, and major factors related to fuels treatments identifies the complexity of the issue.

This literature review addresses:

1. Fire regime in Alaska,
2. Fuels treatment practices and their effectiveness in the Boreal Forest, and

3. Issues related to implementing fuels treatments in interior Alaska with particular emphasis on hardwood stands succeeding to spruce stands.

2.1 Fire Regime in Alaskan Spruce and Hardwoods

Hardwoods (birch, aspen, and poplar) and spruce (white and black) differ significantly with respect to wildfire, in that hardwoods present less of a fire suppression problem than spruce trees. In interior Alaska there are two species of spruce: *Picea glauca* (Moench) Voss and *Picea mariana* (Mill.) BSP, and three important species of hardwood trees: *Betula neoalaskana* Sarg., *Populus tremuloides* Michx., and *Populus balsamifera* L. Interior Alaska forest stands are predominately composed of these species and result in a variety of fuel types (Ottmar and Vihnanek 1998; 2002).

2.1.1 Fire Intensity, Season of Burning, and Fire Size

Fires in interior Alaska's forests tend to be large stand-replacing events in the form of intense crown fires or severe ground fires (Heinselman 1981; Kilgore and Heinselman 1990). Such fires generally occur in the snow-free months when fuels are sufficiently dry for fire spread (Heinselman 1981). Human-caused fires tend to occur in May; June is the peak month for lightning-caused fires (Dewilde 2003; Heinselman 1981). Dewilde (2003) compared two sparsely populated study areas (located in the Galena area and the Yukon Basin area) with a more populated study area located around Fairbanks and showed that in the populated Fairbanks study area there were more fires but fire size was smaller, probably due mostly to fast detection and response of wildfire suppression resources (Table 1).

Table 1. Area, population density, and fire statistics of three study regions in Alaska, 1990-1999 (from Dewilde 2003). Note that the more populated Fairbanks area had the most fires, but the area burned was smaller.

Characteristic	**Fairbanks**	**Yukon Basin**	**Galena**
Area (acres)	15,912,380	28,328,468	31,630,212
Population density (people/million acres)	3,492	51	75
Area burned (acres)	404,292	2,841,807	2,385,718
Area burned (% of total area)	2.5	10	7.5
# of fires	1,857	416	418
Average fire size (acres)	217	6832	5709
Total starts	123	74	78
Lightning starts	20	12	13
Human-caused fires (#/million acres)	97	3	<1
Human-caused fires (% of total)	83	17	4

2.1.2 Fire Type

Fire type in Alaska varies with stand type. Spruce stands (both white and black) tend to be the more difficult places to stop the spread of wildfire (Hardy and Franks 1963; Lutz 1956). A fire burning in a spruce-dominated stand has the opportunity to get into the canopy via ladder fuels and become a crown fire. Black and white spruce have ladder fuels in the form of low crown bases and small dead branches, whereas hardwoods tend to have higher crowns and fewer small branches near the ground due to self-pruning (Johnson 1992). When a fire burns up and through ladder fuels on an individual tree, it is termed torching, and there is an increase in intensity, spotting potential, and chance of crown fire. Such activity adds to the difficulty in protecting human-built structures and suppressing fires.

Crown fires are virtually nonexistent in hardwood stands. The National Wildfire Coordinating Group's (NWCG 1996) *Wildland Fire Suppression Tactics Reference Guide* referring to the different fuel types states that "a crowning spruce fire will normally drop to the forest floor when encountering a stand of hardwoods." Van Wagner (1977) stated that the hardwood *Eucalyptus* spp. dominated forests of Australia and chaparral of the southwestern United States support crown fires; in Canada, only conifers support crown fires due to the high foliar moisture content of hardwoods. Johnson (1992) stated that hardwood foliar moistures are generally 150-200%; whereas, Boreal Forest conifers have <100-150%. Alaska's hardwood fuels are similar to those of Canada, and without a conifer component they rarely if ever support crown fires. Because of foliar moisture and the lack of ladder fuels, hardwood stands are commonly used as natural fuelbreaks in suppression efforts (NWCG 1996).

2.1.3 Fire Frequency

Fire frequency numbers vary across the Boreal Forest (Frelich 2002; Heinselman 1981). Johnson (1992) defined fire cycle ("fire rotation" of Heinselman [1981]) as "the time required to burn an area equal in size to the study area." Yarie (1981) estimated the average fire cycle in Alaska's Porcupine River drainage to be 43 years with 113 years for white spruce, 36 years for black spruce, and 26 years for hardwoods. It seems odd that the fire cycle in hardwoods is only 26 years; in regards to this, Yarie (1981) mentioned that pathological vectors were a major disturbance factor for hardwoods in his study area, and because hardwoods were being replaced by this non-fire disturbance, the fire cycle for hardwoods is likely longer than 26 years. Heinselman's (1981) fire cycle for the larger geographic area of interior Alaska and northwest Yukon Territory was longer than Yarie's: 130 years for open and closed spruce stands, 100 years for birch or black spruce, and 200+ years for floodplain white spruce. Dix and Swan (1970) reported for their 89-stand disturbance study near Candle Lake, Saskatchewan, that, due mostly to wildfire, they did not find a single tree over 120 years old. Appendix 1 presents fire cycle information for the Boreal Forest in Alaska, Canada, and Minnesota.

2.2 Fire Behavior Models

Two different fire behavior models are commonly used to determine surface fire behavior in Alaska. FBP 97, the Canadian Fire Behavior Prediction Software (Hirsch 1996) and the United States' equivalent BehavePlus (Andrews and others 2003; Andrews and Bevins 2003) are the basic Windows software programs that allow users to interface with the models.

Surface fire spread in the BehavePlus software comes from a mathematical model developed by Rothermel (1972). The fuels information is input into the software via standard sets of input to the software that are termed "fuel models" (Albini 1976; Anderson 1982; Rothermel 1972). These "fuel models" use a time-lag fuel moisture concept involving the abundance and moisture of above-ground fuels in different size classes. In order of diameter, and thus ability to increase or decrease in moisture, fuels are classified as 1-hour, 10-hour, 100-hour, and 1000-hour fuels (Andrews and others 2003). These classes correspond to Brown's (1974) planar transect methodology for measuring downed woody debris based on diameter: 0 to .25 inch, .25 to 1 inch, 1 to 3 inch, and greater than 3 inches.

FBP 97 is similar to BehavePlus in that fuels inputs are contained in standard sets, but the sets are termed "fuel types" rather than "fuel models" as in BehavePlus. However, above-ground fuels are not a part of these "fuel types." Instead, three indices of duff moisture, Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), and Drought Code (DC) are used to describe the fuels situation. Duff is an important component of fire behavior in the Boreal Forest where slow decomposition rates lead to a buildup of organic matter (Johnson 1992).

FBP 97 has the ability to model crown fire, whereas BehavePlus does not. NEXUS, a Microsoft Excel spreadsheet based program, can be used to extend BehavePlus's abilities to include crown fire modeling (Scott 1999). Crown fire characteristics can also be evaluated using Van Wagner's (1977) conditions for the start and spread of crown fire (surface fire intensity, crown height, and crown spacing).

There are two major drawbacks to using BehavePlus and FBP 97 in Alaska for evaluating fuels treatments. First, the existing "fuel models" and "fuel types" were developed on a broad scale and are not sufficiently detailed to describe fire behavior in specific areas like interior Alaska (Sandberg and others 2001). Scott and Burgan (2005) recently presented a more elaborate set of fuel models including specific fuel models for

Alaska; however, their set does not include specific fuel models describing fuels treatments. FBP 97 describes spruce only general "fuel types" as either Boreal Spruce or Spruce-Lichen Woodland and also lacks specific models for fuels treatments (Hirsch 1996; Johnson 1992). The second major drawback is the empirical nature of the surface fire spread models; they are better predictors of fire behavior in the geographic locations in which they were developed and these are south of Alaska (Andrews and others 2003; Hirsch 1996; Rothermel 1972; Weber 2001). Wilmore (2001) described the specific issue in FBP 97 of the duff moisture indices being less dynamic than the feather moss profile in interior Alaska black spruce stands. Despite these drawbacks, BehavePlus and FBP 97 are relatively easy to use and do provide insight into questions about treatment efficacy.

2.3 Studies of Fire Behavior in Fuels Treatments

Little information exists on the effectiveness of wildland fuels treatments (Martinson and Omi 2003). In interior Alaska, two fuels treatments (both shaded fuelbreaks in spruce stands) were assessed using computer models of fire behavior (DeFries 2002; Theisen 2003).

DeFries (2002) compared the predicted fire behavior of a thinned, 700 trees per acre, mixed spruce stand with an unthinned, 1,058 trees per acre, mixed spruce stand near the Shannon Park subdivision in Fairbanks, Alaska. The actual weather conditions that supported the nearby Shannon Park wildfire in 1999 were used to make predictions on the two stands. Runs using FBP 97 and BEHAVE software coupled with the NEXUS

(Scott 1999) crown fire prediction program indicated that both stands would have supported a crown fire, thus supporting the argument that the Shannon Park wildfire would not have been easier to suppress had it burned into the thinned stand (Defries 2002).

Theisen (2003) approached the assessment differently. He looked at the before and after treatment conditions of a shaded fuelbreak, thinned and pruned, in a black spruce stand near Badger Gate at Ft. Wainwright, Alaska. Under weather conditions typical for a day during the normal Alaska fire season, BEHAVE software predicted a fire of higher intensity in the treated stand due to increased wind and the grass component. Despite the higher intensity, Theisen (2003), using Van Wagner's (1977) equations for the conditions needed to create crown fire, showed that the treatment reduced the likelihood of crown fire, creating an increase in the severity of weather needed to sustain crown fire.

Weather conditions specified in Defries' (2002) and Theisen's (2003) analyses are important in determining the effectiveness of the treatment. Bessie and Johnson (1995) used Rothermel's (1972) model to predict surface fire intensity and found that all forest stands in the Canadian Rockies reached Van Wagner's (1977) conditions needed for crown fire development under extreme weather conditions. Thus, the models indicated that if weather conditions were sufficiently hot and dry, any forest fuels treatment that leaves a canopy overhead will be ineffective in stopping crown fire.

Based on the above studies, shaded fuelbreaks in black and mixed spruce stands appear to be of limited value and even counterproductive as in the case of Theisen

(2003) where it actually increased fire intensity. Outside of Alaska, where most fuels research has been done, the story appears to be different. Treatments reducing available canopy fuel and increasing height to live crown reduce the probability of crown fire (Graham and others 2004). Case studies show that wildfires are less destructive and easier to control in areas that have been treated for fuels reduction. Weatherspoon and Skinner (1995) analyzed the effect of timber management activities on damage to stands and found, among other things, that site preparation technique and tree species (*Psuedotsuga menziesii* [Mirb.] Franco was less prone to fire damage than *Pinus ponderosa* Dougl. x Laws.) were important in determining fire damage in a plantation. Moore and others (1955) identified less tree death and damage to crowns after a wildfire burned through a New Jersey pine and oak stand previously subjected to a prescribed burn than the control. Martinson and Omi (2003) produced a literature review including this New Jersey study and thirteen similar case studies of areas where fuels treatments have been burned by wildfire; in each case, evidence is presented that the fuels treatment reduced the impact of the wildfire. Unfortunately, quantified evidence (e.g. number of trees damaged or killed in a treated stand versus an untreated stand) is provided in only five of the cases (Martinson and Omi 2003).

2.4 Influences on Fire Behavior

Potential fire behavior is not the only factor that in determines the destructiveness of a wildfire. Agee and others (2000) state that “fuelbreaks are never designed to stop fires but to allow suppression forces a higher probability of attacking a wildland fire.”

Theisen (2003) also noted that a more open canopy resulting from a fuels treatment allows for easier penetration with aerial retardant and water drops. Thus, fire behavior and available suppression resources, together, determine the effectiveness of a fuels treatment (fuelbreak) under any given set of weather conditions. Models are unable to predict what resources will be on hand and what the weather will be when a wildfire occurs in a particular area; consequently, the true efficacy of a fuels treatment cannot be predicted. It is perhaps advisable to use the terms "fuels treatment" and "fuel type break" instead of "fuelbreak" and "firebreak" in order to avoid conveying the erroneous idea that fires will be stopped simply through vegetative manipulation.

2.5 Issues Related to Fuels Treatments

The literature revealed no published data specific to fuels conversion. Only one fuels conversion treatment was found that emphasizes the conversion of mixed spruce-hardwoods stands to hardwood stands. Rogers (2003) describes the North Jarvis stand conversion project, near Delta Junction, Alaska, as a treatment with a goal of promoting hardwood growth. Paragi and Haggstrom (2004a) describe various wildlife habitat projects (prescribed burns and mechanical treatments) with a vegetative conversion goal. While they mention the wildfire hazard reduction, their emphasis was on the creation of wildlife habitat and they did not specifically address wildfire issues.

2.5.1 Soils

The condition of soils after a disturbance that returns a site to the stand initiation stage is important to forest regeneration. Hoyt (1992) states that scarification should aid in the natural establishment of birch. All scarification is not equal however. On Alaska's Kenai Peninsula, Cole and others (1999) found hardwood and spruce regeneration to vary in growth by site preparation treatment. Densmore and Page (1992) explained that exposure of mineral soil is an important result of scarification.

Soil temperature comes into play as a stand matures. Dyrness (1982) showed that as the organic mat thickens soil temperature cools creating an environment more conducive to spruce. Viereck (1970) described both organic horizon thickness as increasing and soil temperature as decreasing with increasing distance from the Chena River in interior Alaska; he described vegetation that followed these changes as distance from the river increased: "15-year-old willow stand on a newly formed gravel bar, a 50-year-old white spruce stand, a 220-year-old white spruce/black spruce stand, and a climax black spruce/sphagnum stand." Viereck and others (1983) showed another potential outcome of this soil temperature change; forest stands occurring on a continuum from warm and dry sites to cool and wet sites were correlated to species change; with aspen populating the warmest sites and black spruce populating the coolest.

2.5.2 Regeneration

Densmore and others (1999) reported on natural regeneration of white spruce on scarified sites in the Bonanza Creek Experimental Forest and found that natural seed sources sometimes regenerate white spruce after a disturbance. Fox and others noted that white spruce seed crops are highly variable and predicting regeneration of white spruce is difficult. Zasada and Gregory (1972) reported that in four years the average birch tree in the Tanana Valley produces enough seed to regenerate areas up to 100 acres; one seed crop amounted to almost 15 pounds, or 9 million seeds per mature tree. Hence, the relative amount of hardwood and spruce in a naturally regenerated stand varies due to differing seed crops and will be unknown in the first few years. To support this, Packee (1990) recommended that regeneration surveys for white spruce not be conducted until a six-inch height has been reached; this is commonly five or six years after a scarification treatment.

2.5.3 Moose

Moose can be either a benefit to fuels management or a source of problems for hardwood regeneration. The general idea of moose habitat creation is to stimulate hardwood growth for use as moose feed (Paragi and Haggstrom 2004a). On the other hand, Andrews (1998) observed that in areas of the Susitna Valley of Alaska where hardwoods were browsed by moose, more light was able to reach the forest floor and benefit the regeneration and growth of spruce in the understory. Moose browsing on hardwoods can also confound the results of regeneration studies (Cole and others 1999).

2.5.4 Slash Treatment

Downed woody debris or slash resulting from fuels treatments is unlikely to decompose in a timely fashion in interior Alaska. Fresh slash can encourage Ips beetle infestations that kill live trees; this occurred at Tanacross, Alaska.[3] Brown and others (1998) found that in subalpine Colorado, windthrown spruce logs persisted for decades and even for more than a century. Swisher (2005) looked at slash in thinned stands in the West Bonanza Creek area near Fairbanks and found that after 22 years, slash loading was 5 to 27 tons more in thinned stands than in a similar unthinned stand. Thus, downed woody debris left on site can cause beetle infestations and remains a fire hazard that remains for many years. Woody debris is an issue that must be addressed in a fuels treatment.

[3] Personal communication. October 2004. Mark Musitano. Ft. Wainwright, AK: USDI Bureau of Land Management Alaska Fire Service.

Chapter 3 Methods

Seven fuels conversion treatments, including an untreated area for control, were identified and implemented between 2003 and 2005:

1. 12-foot spacing of residuals using chainsaw felling and pile and burn cut material (TB);
2. Masticate and leave cut material (ML);
3. Shearblade and leave cut material (SL);
4. Shearblade, windrow, and burn cut material (SB);
5. Shearblade, chunk, and remove cut material (SR);
6. Drum-crush and burn cut material (DB); and
7. No treatment (C).

Letter codes, as identified in parentheses and in Table 2, refer to the technique used for clearing vegetation and what was done with the slash. These codes are used in all figures and text when referring to treatments.

Table 2. Stand treatment codes for the Cache Creek study area.

B = Burn material	M = Masticate
C = No treatment (control)	R = Remove material
D = Drum-crush	S = Shear
L = Leave material	T = Thin

Three 1/10 acre Permanent Sample Plots (PSPs) were established within each treatment. Standard forest growth and yield data were collected within each PSP using procedures outlined by Curtis (1983).

To better understand the effect of burning debris piles on soils, a pilot study was also initiated to investigate soil color change and water repellency.

Land managers involved with fuels treatments were consulted in order to obtain additional information regarding fuels treatments used and the associated costs.

3.1 Site Description

Potential sites were located using aerial photographs of the Cache Creek area, an area previously identified by the Alaska Department of Natural Resources Division of Forestry as in need of fuels treatment; two reasonable locations were identified. Both sites were relatively uniform, accessible, and in the wildland urban interface (Lincoln Creek subdivision lies to the northeast of the study site). The two possible locations were walked in order to verify stand uniformity and the better (more uniform) site was chosen.

The study site is west-northwest of Fairbanks, Alaska at mile 10 of the Cache Creek road (Figures 1 and 2) in Sections 21 and 28, T 4W, R 1N, Fairbanks Meridian. It is on an east-northeast aspect with slopes of 0 to 10%. The study site is on both sides of the road, (Figure 3) west of the Cache Creek bridge, and extends for approximately one-quarter of a mile along the road.

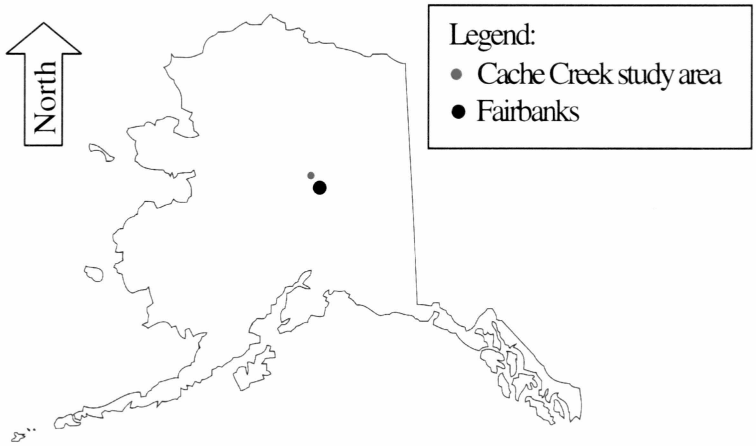

Figure 1. Location of Cache Creek study area. Approximately 15 miles northwest of Fairbanks, AK.

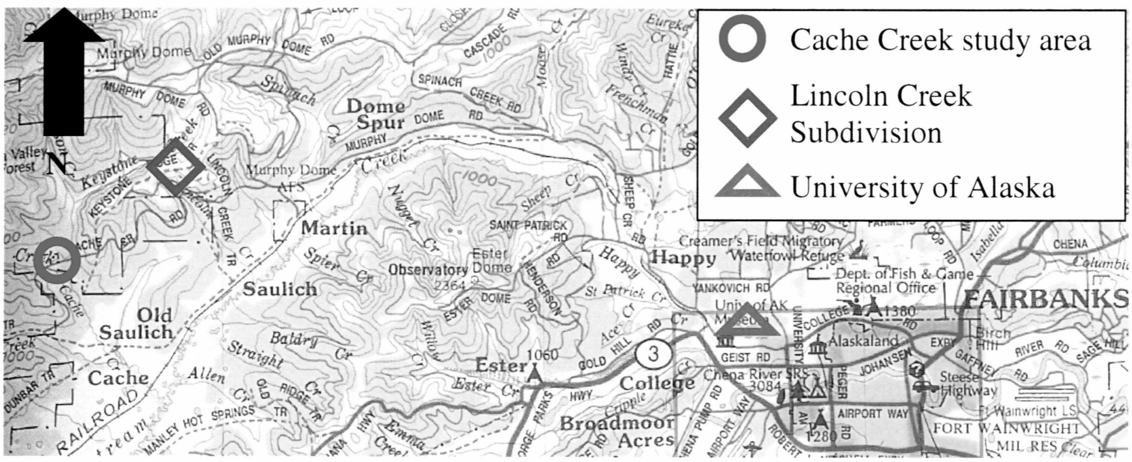

Figure 2. Fairbanks Area vicinity map, one inch equals 5.3 miles. Adapted from DeLorme (2001).

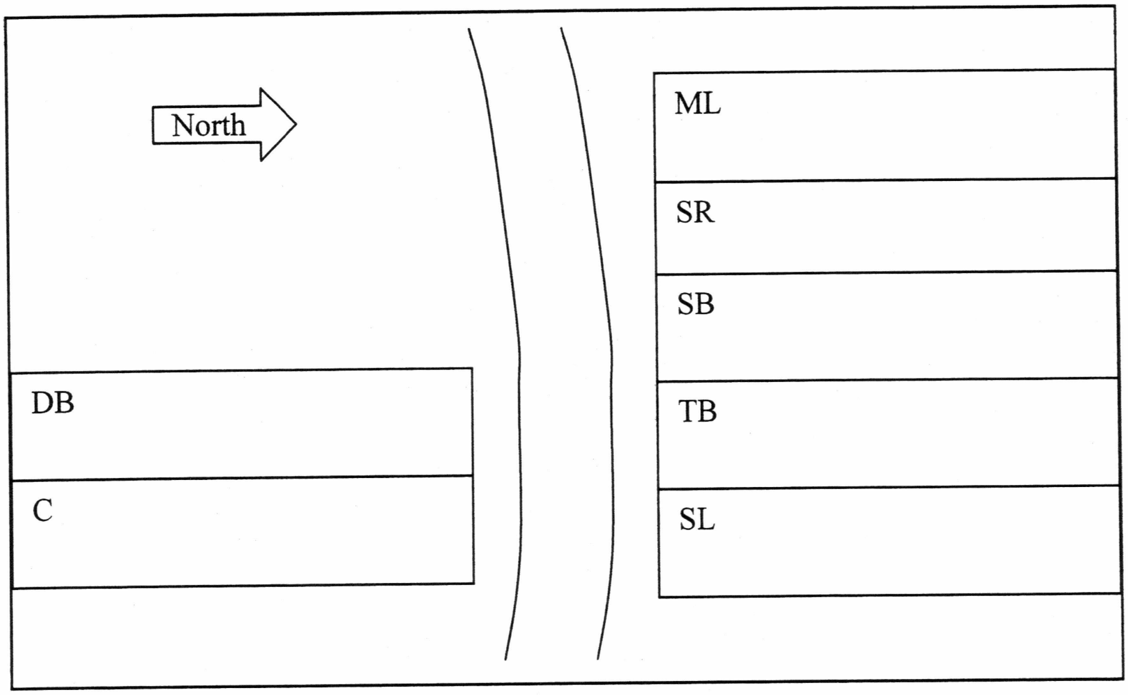

Figure 3. Cache Creek study layout. seven 5.3 acre treatment units at mile 10 of the Cache Creek road.

Soil is mapped as Fairbanks silt loam and is classified as a coarse-silty, mixed, superactive Typic Eutrocryept that is permafrost free (to a depth of 40 inches) (Furbush and Schoephorster 1977; Mulligan 2005). These soils generally have an organic layer of 1-6 inches, are moderately acid to neutral, and have the following color characteristics:

- A horizon– hue of 7.5YR or 10YR, value of 3 or 4, and chroma from 2 to 4;
- Bw horizon– hue from 7.5YR to 2.5Y, value from 3 to 5, chroma from 2 to 4;
- C horizon– hue from 10YR to 5Y, value from 4 to 6; chroma from 2 to 4 (Mulligan 2005).

The last major disturbance in the area was a 1957 wildfire that encompassed the entire study site and surrounding area. In 2003, the site was dominated by a single-cohort, mixed hardwood/spruce stand. The stand was composed of a hardwood overstory with mixed black and white spruce in the understory; trees were 45 years old and younger.

3.2 Treatments

Treatments were arranged to create both a functional fuelbreak and a demonstration area where visual comparison of the treatment units could be made. Treatment units (Figure 3, 1,000 by 230 feet) were flagged and boundaries painted on trees. Initial treatments were assigned to units using a random number table. After shearblading and windrowing, fuel arrangement and equipment access presented issues so units SB and SR were switched. The switched SB treatment unit had more compact windrows and thus was a better candidate for burning; the switched SR treatment unit, adjacent to an access road created by the shearblade operator, provided easy access for material removal. The DB unit was added to the experiment in early 2004 after the initial treatment design was established and 2003 data collection was completed because the opportunity to use a drum crusher presented itself. Thus, it must be noted that the statistical analysis requirement for randomness was violated.

3.2.1 12-Foot Spacing with Thin, Pile, and Burn Material (TB)

A contractor completed chainsaw thinning and pile burning in September-October of 2003. This was the only treatment where a canopy was retained. In preparation for the contractor, leave trees were marked at approximately 12-foot intervals. This spacing was thought to create a sufficiently open canopy for hardwood regeneration. Hardwoods (birch, aspen, or poplar) were the preferred leave trees; however, a few white spruce were left where no other suitable leave trees were present. A number of marked trees were flagged to be cut as burn pile locations to mitigate the concern that heat from the burning piles might kill adjacent leave trees. These pile locations were within the treatment unit but off of the PSPs so that comparisons using the PSPs in this treatment would not be confounded by burned soil, tree mortality, or increased tree spacing.

To address questions concerning the effect that pile burning has on soil microsites, the soils underneath three burn piles were sampled before and after burning for soil color and water repellency within the unit. A soil water drop penetration test (Krammes and DeBano 1965) was conducted to determine if burning had an effect on soil water repellency. Before burning, one soil core (extracted with a 12-inch by 2 3/8-inch plastic tube) was removed and the soil color was measured (at 0-2 inches, 2-4 inches, and 4-6 inch depths) within the core. Soil color was measured, using Munsell soil color charts (GregtagMacbeth 2000). This color measurement was repeated at four additional locations within each burn pile without taking a core sample. In 2004 (after burning was complete), four soil cores were taken from each pile location according to the diagram in Figure 4; the new scheme differed from the previous year both in number of measurements (4 versus 5 per pile) and in that the measurements were intentionally taken in a line from the center of the burn pile to outside the pile. The systematic system of measurement location enabled comparison of 2003 and 2004 measurements and among 2004 measurements from different locations within and adjacent to the piles. The cores were separated into four layers (organic or ash, 0-2 inches, 2-4 inches, 4-6 inches), soil color was noted, and then the layers were placed in paper bowls where they were allowed to air-dry before applying the water drop test.

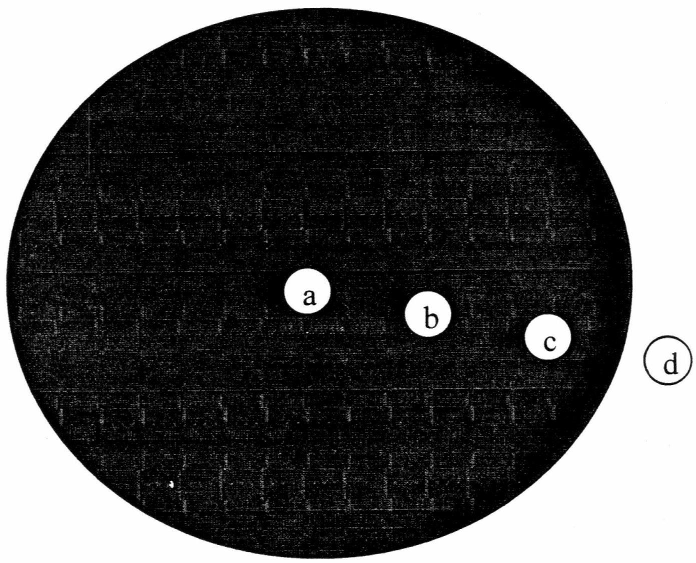

Figure 4. 2004 Burn pile color change and water repellency sampling diagram. Each burn pile's soil cores are labeled by position (a-d) from the center of the pile to the outside.

For each soil layer of a core, multiple drops of tap water were applied with an eyedropper. If a bead formed in any part of the layer, the time it took to dissipate was measured for up to 60 seconds. A layer was termed water repellent if it maintained a single bead of water on the soil surface for 5 seconds or longer and highly water repellent if a bead of water was maintained for 60 seconds or longer (DeBano 1981; Henderson and Golding 1983).

3.2.2 Masticate and Leave Material (ML)

A 2003 version of the Fecon BH-120 Bull Hog attached to a Franklin 4550 S2 carrier (Figure 5) was used to masticate the vegetation in the fall of 2003. Only the ML treatment data include calculations of chip depth. In order to qualitatively evaluate the effect of multiple passes with the machinery, the treatment unit was subjected to different levels of mastication (one pass, two passes, and three passes) as depicted by the different patterned areas in Figure 6. The rationale for doing multiple passes was to track man hours in order to determine if the additional cost could be justified because of more thoroughly mixing woody material into the soil, and thereby reducing the amount of fuel available for consumption by wildfire. The three PSPs within the treatment unit received three passes of mastication.

3.2.3 Shearblade and Leave Material (SL)

Shearblading was done in February 2004. Shearbladed material was left on site. A Caterpillar D8H dozer fitted with a Rome KG shearblade (Figure 7) was used for the

Figure 5. Fecon BH-120 Bull Hog attached to a Franklin 4550 S2 carrier on the Masticate and Leave Material (ML) treatment unit, fall 2003.

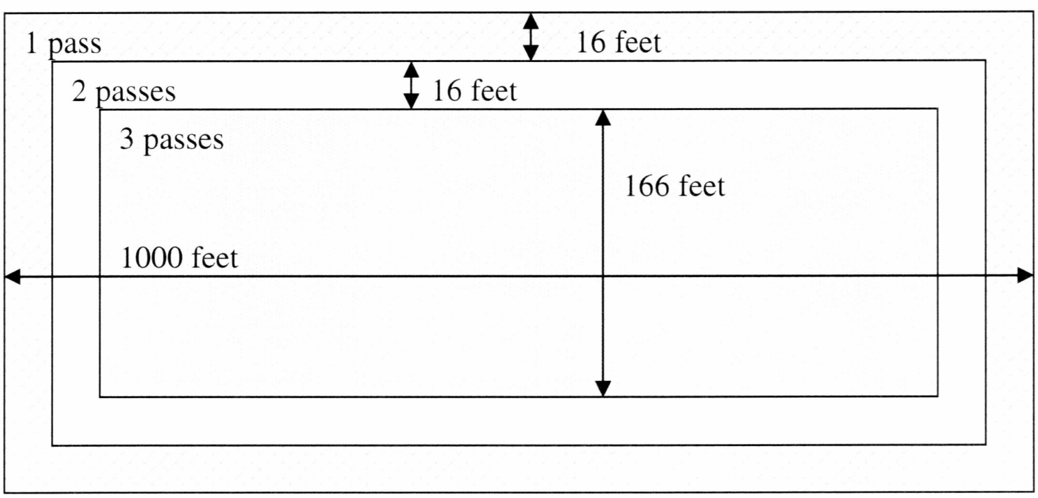

Figure 6. Diagram of Masticate and Leave Material (ML) treatment passes.

Figure 7. Caterpillar D8H dozer fitted with a Rome KG shearblade on Cache Creek road, February 2004.

three shearblade treatments. The operator inadvertently partially cleared the three PSPs when exiting the treatment unit. Because the operator was unaware of PSP locations, data from PSPs is treated as within the range of variability for this treatment. It should be noted, however, that the PSPs have visibly less material on them than the majority of the treatment unit.

3.2.4 Shearblade, Windrow, and Burn Material (SB)

Shearblading was done in February 2004 using the same equipment and contractor as the SL treatment. Shearbladed material was windrowed with the shearblade and burned in September of 2004 by the Alaska Department of Natural Resources Division of Forestry personnel. Two engines and two four-wheelers were utilized during burning operations to prevent fire escape and aide in moving within the treatment unit.

3.2.5 Shearblade, Chunk, and Remove Material (SR)

Shearblading was done in February 2004 and was the same as the SB treatment except that windrows were not burned. Chunks were ground with a CMI Maxigrind 460 multi purpose grinder (Figure 8). A contractor, in September-October of 2005, hauled chunks out to the Cache Creek road in a dump truck and spread them as road fill.

Figure 8. CMI Maxigrind 460 multi purpose grinder at Cache Creek Shearblade, Chunk, and Remove Material (SR) treatment unit, 2005. Bulldozer in background was used to help move the grinder when it became stuck in the soft soil (courtesy of Alaska Department of Natural Resources Division of Forestry).

3.2.6 Drum-Crush and Burn Material (DB)

A 6- by 12-foot barrel crusher with blades pulled by a Caterpillar D7 dozer (Figure 9) was used to crush the trees in March of 2004. The dozer created a fireline around the

Figure 9. Caterpillar D7 dozer with drum-crusher near Cache Creek study area, March 2004 (courtesy of Alaska Department of Natural Resources Division of Forestry).

inside edge of the treatment unit to prepare the unit for a broadcast burn. The burn was attempted in early October 2004 and was unsuccessful due to lack of fuel consumption. The burn was aborted until more favorable weather and fuel moisture conditions occured and is still unburned. This treatment was added to the project in March of 2004 when the opportunity to use a drum-crusher presented itself and the Alaska Department of Natural Resources Division of Forestry wanted to evaluate the use of the drum-crusher. Only treated two of the three PSPs were treated (PSP 12 was not treated) due to difficulty locating treatment unit boundaries.[4]

[4] Personal communication. March, 2004. Kathryn Pyne. Alaska Department of Natural Resources Division of Forestry.

3.2.7 Control (C)

The control area received no treatment. PSPs were established within the unit.

3.3 Permanent Sample Plots (PSPs)

Three PSPs were installed in each treatment unit for the purpose of replication. The individual PSPs were based on the approach described by Curtis (1983) and utilized by the University of Alaska Fairbanks Forest Growth and Yield Program (Packee 2003). Initially, PSPs were placed systematically within the stand (Figure 10). The goal was to have each square 66 by 66 foot PSP approximately 80 feet (roughly twice the initial estimate of stand canopy height) from the treatment unit boundary in order to avoid edge effects from surrounding vegetation or treatments. Because the object was to compare similar pieces of ground, some PSPs were moved from the systematic location displayed in Figure 10 in order to avoid minor drainages or survey lines. Thus, again, the statistical requirement of randomness was violated out of necessity.

Data collected are provided in Table 3. Downed woody debris and forest floor depth were measured using a single 100-foot permanent planar transect per PSP (Brown 1974). Brown's (1974) methodology involved measuring the forest floor depth at 10 points along a transect and tallying woody debris that crosses the transect using four size classes: 0 to .25 inch, .25 to 1 inch, 1 to 3 inch, and greater than 3 inches. The diameter of any piece of woody debris larger than 3 inches was actually measured because of its larger contribution to the total woody debris. The tally and measurements were then converted into tons/acre using Brown's (1974) equations. In 2004, four

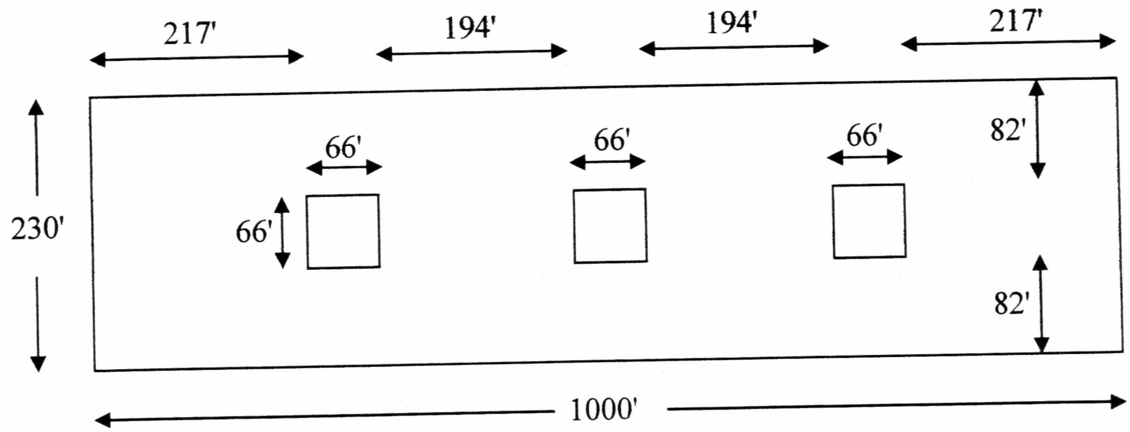

Figure 10. Initial treatment layout, showing the three Permanent Sample Plots (PSPs) inside a treatment unit.

planar transects per PSP were used to measure chip depth in the ML treatment because of the variability in depth present.

Because of design layout, sides of the PSP squares were placed approximately north-south and east-west. The northwest corner was used as the starting point for the permanent planar transects that extended approximately 6.5 feet outside the southeast corner. A 40-inch deep soil pit was dug near each PSP to better describe and understand the site.

Within each 1/10-acre PSP, five 1/250-acre circular subplots were established for subsampling regeneration and individual trees. One subplot was placed at the PSP center and the other four were placed between the center and the four corners of the PSP (Figure 11). Tree height and length of live crown were measured to the nearest foot and diameter at breast height was measured to the nearest 0.1 inch.

Table 3. Data collected on Permanent Sample Plots (PSPs) for Cache Creek study area.

Tree data	**Soil data**	**Other**
Tree species	Landform	GPS coordinates
Diameter at breast height	Texture	Aspect
Height	Color	Slope %
Length of live crown	Litter/duff depth	Elevation
Visual defects		Contour
Crown class		Non-tree species present
Age		Downed woody debris
Regeneration		Photos from NW corner
Age (cores)		Canopy photos up from center
Dead snags		
Canopy cover		

The PSPs within the DB treatment were added after the initial study design and snow on the treatment unit limited the collection of initial data to slope, GPS coordinates, aspect, elevation, contour, photo points, and tally and measurement of trees larger than 0.5 inches in diameter at breast height. Other data were assumed to be similar to the initial data on other treatment units.

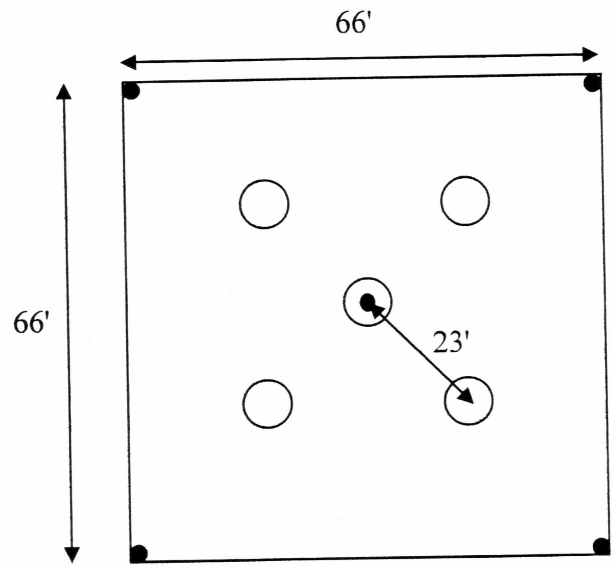

Figure 11. Permanent Sample Plot (PSP) layout.

3.4 Interviews

Personnel in the field of fuels management in interior Alaska were contacted to obtain information on acres treated, treatment method, dollar costs of performing the treatment, location, and whether and what data were available for their treatments. Agencies contacted included: Alaska Department of Natural Resources Division of Forestry, USDI Bureau of Land Management Alaska Fire Service, USDI National Park Service, Tanana Chiefs Conference, and U.S. Army Alaska. The intent of the interview effort was simply to find out whether fuels management practices were occurring in interior Alaska. No formal survey was conducted.

3.5 Data Analysis

The design of the study was exploratory in nature and, thus statistical analyses of data are limited. Data are presented for the stand as a whole in 2003 and for individual treatments and PSPs in 2004. Available data for each treatment vary because operational timeframes were different for each treatment.

The 2003 stand photos and trees per acre were compared with similar stands described in Ottmar and Vihnanek's (2002) stereo photo series. Comparisons were made between treatments with respect to the amount of material left on site, regeneration, and the dollar and man/machine hour costs. Treatments are then discussed individually, along with the available data for each treatment.

A single factor ANOVA was used to compare regeneration data. Important points about this ANOVA include:

1. The study was not created with an ANOVA in mind.
2. Assumptions of ANOVA model 1 from Neter and others (1996) were violated and are:
    a. Each probability distribution has the same variance, and
    b. The responses for each factor level are random selections from the corresponding probability distribution and are independent of the responses for any other factor level.

The probability distribution for the ML treatment has more variance than the TB and SL treatments. The requirement for randomness was violated because PSPs were not randomly located nor were treatment units randomly assigned.

3. Pseudoreplication as described by Hurlbert (1984) is present in the analysis because all three PSPs are within a single treatment unit (spatially related) rather than three randomly located replications of each treatment
4. The ANOVA test was decided upon after data collection, so a conclusion that the treatments were different would be less decisive than a test done where a hypothesis was formed before the test.

Thus, interpretation of ANOVA results must be done with caution.

Downed woody debris and forest floor fuel loadings were calculated according to the planar transect method outlined by Brown (1974). However, Brown (1974) recommended that better specific gravity constants be obtained for better results. In order to improve these calculations, the *Picea mariana/glauca* constants from FMH software (Sydoriak 2001) were used for all data. Another deviation from Brown's (1974) methodology was that the planar transects were permanent rather than random. This was done so that a more meaningful before and after comparison could be done for the slash loadings on the site.

Chapter 4 Results and Discussion

Results and discussion are presented first for the treatment units prior to treatment (2003), second, for each individual treatment unit post treatment, and third, for comparisons among treatments. Statistical analyses are limited due to the exploratory nature of the study.

4.1 2003 Stand Data

Prior to any fuels treatment, the stand at the Cache Creek study area most closely matched, in terms of trees per acre by size, the AKHD 05 (Alaska Hardwoods stand number 05) stand of Ottmar and Vihnanek (2002) as supported by Permanent Sample Plot (PSP) data. Table 4 shows trees per acre by size class for the two stands. Most (>60%) trees in the Cache Creek stand were in the 0 to 2-inch-diameter class and the fewest (<6%) were in the 4 to 9-inch-diameter class. The Cache Creek stand contained more trees in all size classes and a comparison of Figures 12 and 13 show that the Cache Creek stand is also different in structure compared to the AKHD 05 stand. However, using trees per acre and the stereo photos provided by Ottmar and Vihnanek (2002), the Cache Creek stand still falls into the AKHD 05 classification.

Mean diameters for hardwoods and spruce in the Cache Creek stand are presented in Figure 14; note the higher number of small-diameter spruce trees in the understory and the low number of hardwoods in the overstory. Diameter distributions for each treatment unit are presented in Figure 15. Although the treatment units are not exactly

Table 4. Trees per acre at Cache Creek study area compared to AKHD 05 (Alaska Hardwood stand number 05). AKHD data from Ottmar and Vihnanek (2002).

Diameter (inches)	**Cache Creek Study Area (trees per acre)**	**AKHD 05 (trees per acre)**	**Percent Difference**
<2	3,798	3,338	14%
2-4	1,290	1,241	4%
4-9	296	34	771%
>9	0	0	0%
Total	5,384	4,613	17%

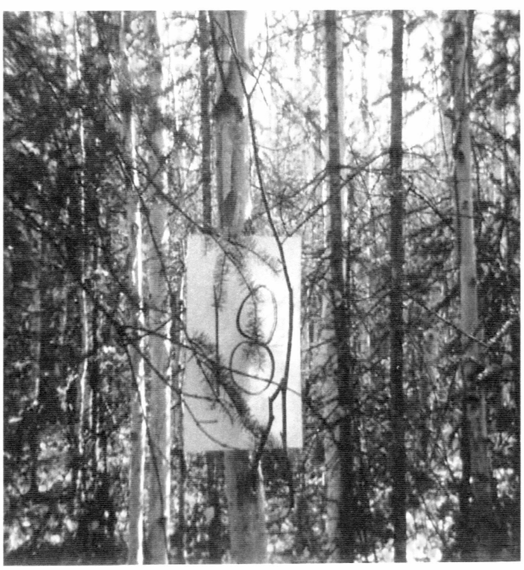

Figure 12. Permanent Sample Plot (PSP)18, Cache Creek study area.

Figure 13. AKHD 05 (Alaska Hardwood stand number 05) (from Ottmar and Vihnanek 2002).

identical, they are sufficiently similar to one another. In summary, all treatment units are within a dense stand with many small trees and few larger trees.

The stand in 2003 consisted of thousands of stems per acre with a hardwood-dominated overstory and a spruce-dominated understory. The 2003 data for downed woody debris and duff depth are incomplete; data for PSPs 10-12 were lost, and for PSPs 19-21, data were not collected because those PSPs were added after snow cover prohibited measurement. Visually, however, no difference was exhibited between PSPs with data and those without. Table 5 shows the average downed woody debris by size class and the average duff depth. Average tons/acre for downed woody debris in the study area was 2.82 and the average duff depth was 2.39 inches. Most of the downed woody material was small (<3 inches) in diameter which suggests that it is available fuel for wildfires. Appendix 2 presents the planar transect data by PSP in its entirety.

Soil pits were dug on PSPs 1-18. They were not completed for PSPs 19-21 (DB treatment unit) because that unit was added to the study the winter 2003-2004 that the drum-crushing occurred. Appendix 3 provides a summary of the soil color and organic layer depths observed in the soil pits. In all but two soil pits, charcoal was observed to be present in the soil profile at varying depths. Soil color was mostly within the range described by Mulligan (2005) for the Fairbanks series , the exception being that the A horizons were not always within the hues of 7.5YR and 10YR andin some samples 2.5Y and 5YR.

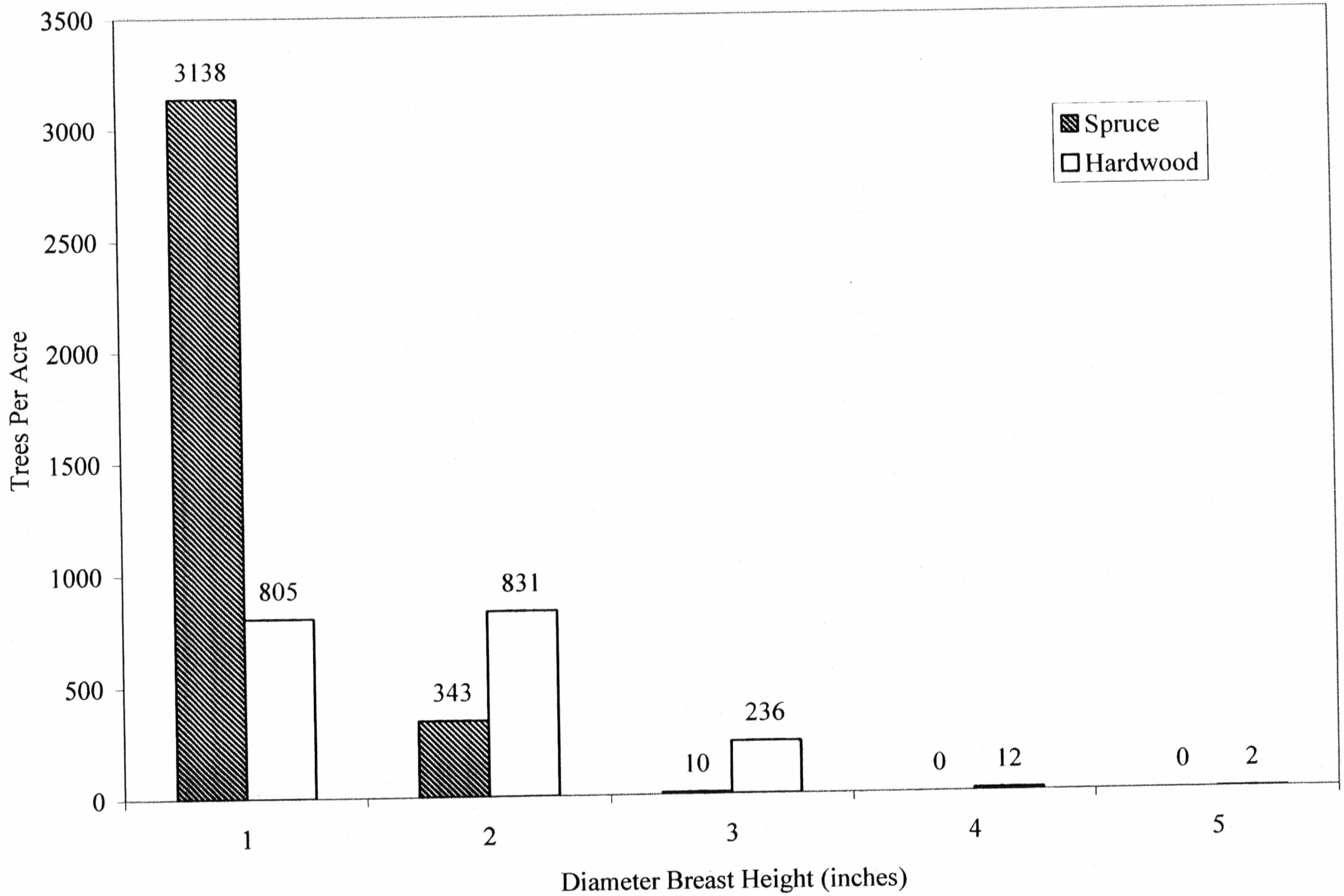

Figure 14. 2003 mean hardwood and spruce diameter distribution for all Cache Creek study treatment units, combined (n=21).

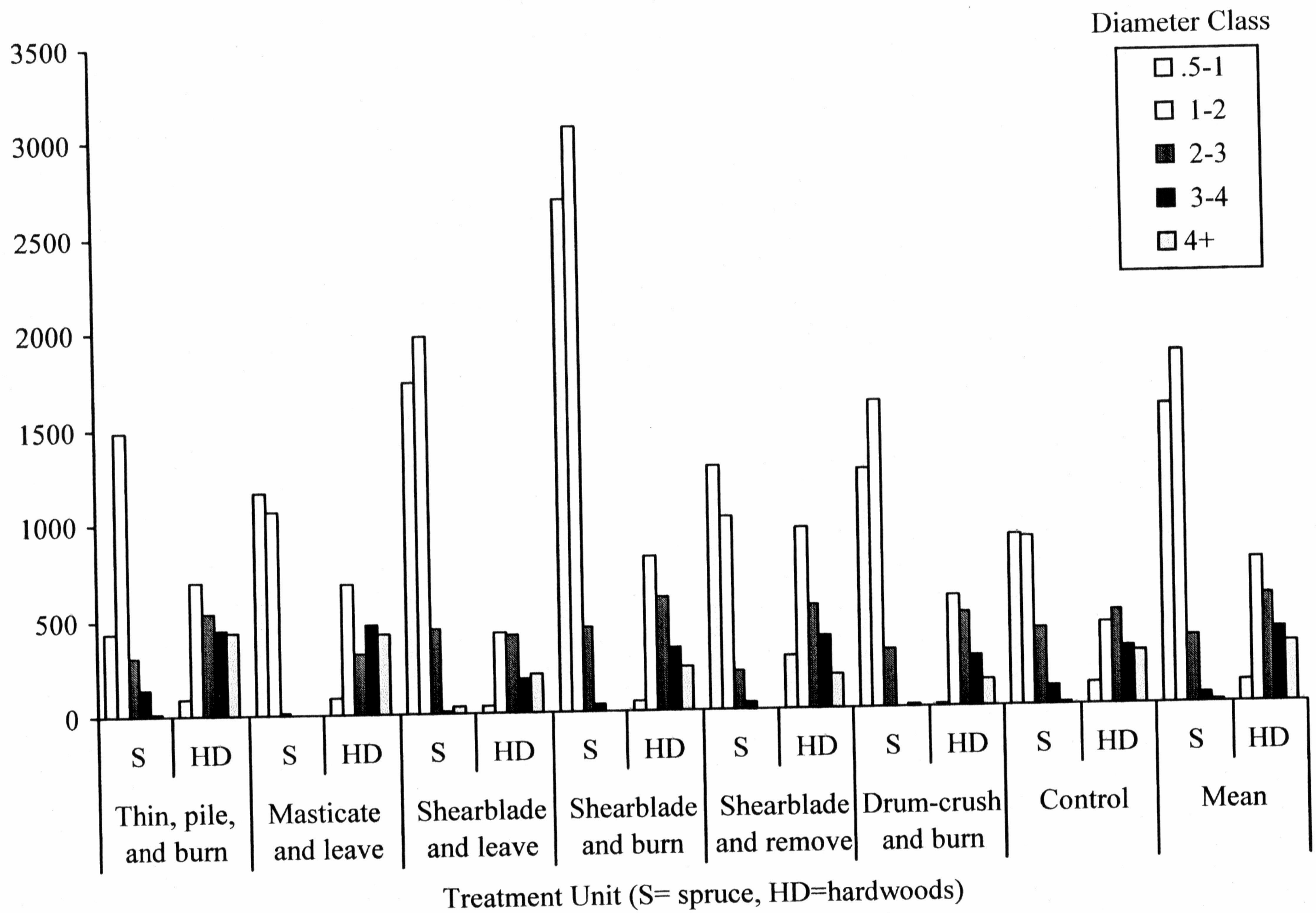

Figure 15. 2003 diameter distribution by treatment unit for the Cache Creek study area.

Table 5. Downed woody debris and duff depth summary 2003 for Permanent Sample Plots (PSPs) 1-9 and 13-18, data for other PSPs missing.

Size Class (inches)	Tons/Acre
<0.25	0.16
0.25–1	1.11
1–3	0.88
>3 sound	0.67
>3 rotten	0.00
Total woody debris	2.82
Duff depth	2.39

4.2 12-Foot Spacing with Thin, Pile, and Burn Material (TB)

Figure 16 shows the open stand created in the TB unit after treatment completion. The photo is also a good reference for interpreting the downed woody debris data (Tables 6 and 7). Table 6 shows that downed woody debris decreased overall by 86% and Table 7 shows that the debris is distributed throughout the woody debris size classes. The litter layer was not measured in 2003, so comparisons of forest floor depth can only be made using the duff layer. Table 6 shows an increase in the duff layer to 133% of the depth before treatment. An explanation for this increase is unknown.

Regeneration did occur on this site even though mineral soil was not exposed and the total forest floor layer averaged 2.64 inches (Table 7). Regeneration was also observed off the PSPs in the areas subjected to debris pile burns.

The TB treatment was relatively expensive; it took the most man hours, but was not the most expensive in dollar terms. It took 104.2 man-hours per acre (Table 8) at a cost

Figure 16. Thin, Pile, and Burn (TB) treatment unit, 2004.

Table 6. Mean downed woody debris and duff depth percent change from before to after treatment and post treatment fuel arrangement by treatment.

Treatment	**Woody debris**	**Duff**	**Fuel arrangement post treatment**
TB	86%	133%	mostly consumed, 300 trees per acre
ML	no data	55%	mulch layer
SL	690%	59%	scattered, down, large pieces
SB	542%	69%	mostly consumed
SR	no data	no data	removed
DB	no data	no data	mostly consumed
C	no change	no change	no change

Table 7. Downed woody debris summary 2003 and 2004 for the Thin, Pile, and Burn (TB) treatment unit. Note that the litter layer was not measured in 2003.

Descriptor	Size Class (inches)	2004	2003
Tons/Acre	0–.25	0.06	0.35
	0.25–1	2.05	1.37
	1–3	0.94	0.75
	3+ sound	0.00	0.15
	3+ rotten	0.00	0.00
	Total woody	3.05	2.62
Inches	Duff depth	1.45	0.93
	Litter depth	1.19	---
	Total floor	2.64	---

Table 8. 2003–2005 Cache Creek man/machine-hour costs for 5.3-acre treatment units (data from contractors and K. Pyne [Alaska Department of Natural Resources Division of Forestry]).

Treatment	Man hours/ acre	Machine hours/acre
Chainsaw, pile, and burn	104.2	
Masticating head 1st pass		6.7
Masticating head 2nd pass		3.8
Masticating head 3rd pass		3.4
Masticating head 3 passes		13.9
Shearblade and leave		0.6
Shearblade and windrow		1.4
Burn windrows	10.2	3.4*
Drum-crush		0.7
Tub-grind		72.0**
Spread chunks		22.0

*Two engines and two 4-wheelers
**Tub grinder and a dozer to get the grinder unstuck

of $2,700.00 per acre (Table 9). The stand is clean looking relative to the others, and thus may be perceived by the public as a more acceptable fuels conversion alternative because of aesthetics. Aesthetics aside, chainsaws may be the preferred alternative in areas where topography or proximity to buildings prohibits the use of large machinery.

Piling and burning of the debris is not the only option for slash disposal; however the simultaneous cutting and burning piles worked well on this treatment. The question of the long-term effect of burning piles remains unknown. Pile burning did cause a color change in the soil and water repellency was present to some degree in both burned and unburned soil samples.

Water repellency data are presented in Table 10. Water repellency occurred both in cores subjected to burning and unburned cores. Only one soil core (Pile number 1, 2004c) showed no evidence of water repellency. This core was inside the burned area but near the edge of the burn. In one case (Pile number 1, 2003) every water droplet formed a bead on the 2 to 4 inch layer. In all other cases, droplets of water did not bead. Since each layer of soil was mixed when transferring it to a paper bowl for drying purposes, it is difficult to say whether or not a specific horizon of water-repellent soil resulted from burning. Soils exhibited water-repellent properties in the organic horizon of all unburned samples; this water repellency was always observed in the lower, fermentation (Oe) and humus (Oa) horizon of the samples.

Table 11 shows the soil color data for the same soil cores used in the water repellency experiment and four additional color observations from 2003. Soil color change was detected between the 2003 samples and the 2004 samples from outside the burned piles compared to the samples under the burned piles. All but one unburned sample color was a 2.5YR hue in the Munsell Soil Color Chart. Hues of 7.5YR and 10YR were observed within the burned area and in one case outside the burned area (2004 d, see Table 11). The 7.5YR and 10YR hues occurred toward the center of the

Table 9. Estimated fuels treatment cost by location and agency for interior Alaska.

Primary agency	Contact/ interview Date	Location	Fuels con-version	Treatment type	Acres	Cost/acre
Tanana Chiefs Conference	Doug Hanson 1/28/2004	Tanacross	No	Shaded fuelbreak/ burning cost not included	51.0	$2,814.81
		Western Tanana Flats	No	Fireline for prescribed burn	5.2	$6,110.47
		Nulato	No	Clearcut/pile/ Burn	14.0	$5,618.96
		Northway	No	Ongoing	Ongoing	Ongoing
		Allakaket	No	Ongoing	Ongoing	Ongoing
		Healy Lake	No	Shaded fuelbreak	Ongoing	Ongoing
U. S. Air Force	Heidi Young 12/01/2004	Clear Air Force Base	Yes	Shearblade	181.0	$181.00
			Yes	Hydroaxe	Unreported	Unreported
U. S. Army Alaska/ USDI Bureau of Land Management Alaska Fire Service	Dan Rees 2/12/2004	Shannon Park	No	Shaded fuelbreak	10.0	Unreported
		Hamilton Acres	No	Shaded fuelbreak	3.0	Unreported
		Badger Gate	No	Shaded fuelbreak	3.5	Unreported
		Jarvis Creek (Delta)	Yes	Shaded fuelbreak	36.0	Unreported
			Yes	Shearblade	Ongoing	Unreported
			Yes	Hydroaxe	Ongoing	Unreported

Table 9. (continued)

Primary agency	Contact/ interview Date	Location	Fuels con-version	Treatment type	Acres	Cost/acre
Alaska Department of Fish and Game	Tom Paragi 11/30/2004	Nenana Ridge	Yes	Prescribed fire	70.0	$320.00
			Yes	Felling and dozer windrowing	30.0	$1,000.00
		Nenana Ridge/ Two Rivers	Yes	Chainsaw felling	473.0	$230.00
		Heritage Forest (North Pole)	Yes	Shearblade	207.0	$75.00
		Delta Bison Range	Yes	Feller buncher and piling	7.0	$370.00
			Yes	Shearblade and windrow	148.0	$125.00
Department of Natural Resources Division of Forestry	Kathryn Pyne 11/30/2004	Cache Creek (this study)	Yes	Shearblade	10.8	$350.00
			Yes	Shearblade and windrow	5.3	$450.00
			Yes	Drum-crush	10.0	$480.00
			Yes	Chainsaw, pile, and burn	5.3	$2,700.00
			Yes	Masticating head 1 pass	5.3	$2,311.50
			Yes	Masticating head 2 passes	4.4	$3,622.50
			Yes	Masticating head 3 passes	3.6	$4,795.50
	Marc Lee 9/27/2005		Yes	Chunk grinding	5.3	$2,768.52
			Yes	Chunk hauling	5.3	$1,074.07
			Yes	Spread chunks in road	5.3	$462.96
	Kathryn Pyne 9/29/2005	Little Chena	Yes	Shearblade	270.0	$161.00

Table 9. (continued)

Primary agency	Contact/ interview Date	Location	Fuels con-version	Treatment type	Acres	Cost/acre
USDI National Park Service	Dan Warthin 11/29/2004	Denali Front Country	No	Shaded fuelbreak, fuel removed from site	24.0	$12,166.67
	Marsha Henderson 11/29/2004	Stampede Trail	No	Chainsaw felling	3.0	Ongoing
		Remote Cabins	No	Chainsaw felling	.75-1 acre/cabin	Ongoing
		Toklat Road Camp	No	Chainsaw felling	10.0	Ongoing

*All data are estimates from personal conversations concerning fuels treatments that occurred between 1996 and 2005, except data from Tom Paragi that is also in a poster (Paragi and Haggstrom 2004b).

Table 10. Water repellency data; where: R= repellent (bead for 5 seconds or more), H= highly repellent (bead for 60 seconds or more), X= no water repellency noted, and NA= no ash present.

Pile #	**Core**	**Burned?**	**Duff**	**0 – 2”**	**2 – 4”**	**4 – 6”**
1	2003	No	**R**	**H**	**H**	X
1	2004a	Yes	NA	**R**	X	X
1	2004b	Yes	NA	**H**	X	X
1	2004c	Yes	X	X	X	X
1	2004d	No	**H**	X	X	X
2	2003	No	R	X	X	X
2	2004a	Yes	X	**H**	X	X
2	2004b	Yes	X	X	**R**	X
2	2004c	Yes	X	X	**R**	X
2	2004d	No	**H**	X	X	X
3	2003	No	**H**	**R**	**R**	X
3	2004a	Yes	X	**H**	X	X
3	2004b	Yes	NA	**R**	X	X
3	2004c	Yes	NA	**R**	**R**	X
3	2004d	No	**R**	**R**	X	X

burn piles (except pile 2, 2004 d). The hue change was observed to a depth of at least six inches and is due to increased oxidation of iron minerals caused by increased temperature towards the center of the pile. Reddish hues in areas unburned during this study (5R, 7.5YR, and 10YR) were observed in soil pits (Appendix3) as well as pile 2, 2004 d. This coloration is likely due to heat from the 1957 wildfire that occurred on the study site and must be considered when interpreting the color data.

4.3 Masticate and Leave Material (ML)

The ML treatment unit differed from other treatment units in that all the material was left on site in a mulched (or chipped) form (Figure 5). Downed woody debris was not

Table 11. Soil color data for Thin, Pile, and Burn (TB) treatment unit. 2003 samples labeled e are soil cores from the water repellency study.

		2"		4"		6"	
Pile	Sample	2003	2004	2003	2004	2003	2004
1	a	2.5Y4/2	7.5YR 3/2	2.5Y 4/3	10YR 5/3	2.5Y 4/3	10YR 6/3
1	b	2.5Y 4/3	10YR 3/2	2.5Y 4/3	10YR 3/3	2.5Y 4/3	10YR 3/3
1	c	2.5Y 4/3	2.5Y 4/3	2.5Y 4/3	2.5Y 6/2	2.5Y 4/3	2.5Y 6/3
1	d	2.5Y 5/3	2.5Y 4/3	2.5Y 5/3	2.5Y 5/3	2.5Y 5/3	2.5Y 5/3
1	e	2.5Y 4/3		2.5Y 4/3		2.5Y 4/3	
2	a	2.5Y 5/3	7.5YR 2.5/1	2.5Y 5/3	10YR 5/3	2.5Y 5/3	10YR 5/3
2	b	2.5Y 3/2	10YR 6/2	2.5Y5/4	2.5Y 6/4	2.5Y5/4	2.5Y 6/4
2	c	2.5Y5/4	2.5Y 5/3	2.5Y5/4	2.5Y 6/3	2.5Y5/4	2.5Y 6/3
2	d	2.5Y4/2	10YR 5/3	2.5Y5/3	2.5Y 5/3	2.5Y5/3	2.5Y 5/3
2	e	2.5Y4/2		2.5Y5/3		2.5Y5/3	
3	a	2.5Y 4/3	10YR 3/2	2.5Y 4/3	2.5Y 5/2	2.5Y 4/3	2.5Y 5/3
3	b	2.5Y 4/2	10YR 4/3	2.5Y 4/3	10 YR	2.5Y 4/3	10YR 5/3
3	c	2.5Y 4/3	10YR 5/3	2.5Y 4/3	10YR 5/3	2.5Y 4/3	10YR 5/3
3	d	2.5Y 4/3	2.5Y 5/3	2.5Y 4/3	2.5Y 4/3	2.5Y 4/3	2.5Y 4/3
3	e	2.5Y 4/2		2.5Y 5/3		2.5Y 5/3	

measured in 2004 because the mulch layer replaced it; the mulch layer was measured as part of the forest floor. Forest floor measurements revealed that this treatment was unsuccessful in mixing the vegetative material into the mineral soil because the duff layer was still intact. This was true of one, two, and three passes with the masticating head. Figure 17 shows the mean duff, chip, and overall organic horizon thickness for the ML treatment unit; overall organic horizon thickness was approximately 6.5 inches thick after treatment. The duff layer was largely intact, relatively undisturbed by the masticating head. The mulched layer of woody material was nonuniform throughout the site. Visual observations showed regeneration occurring in areas with thin or no organic material.

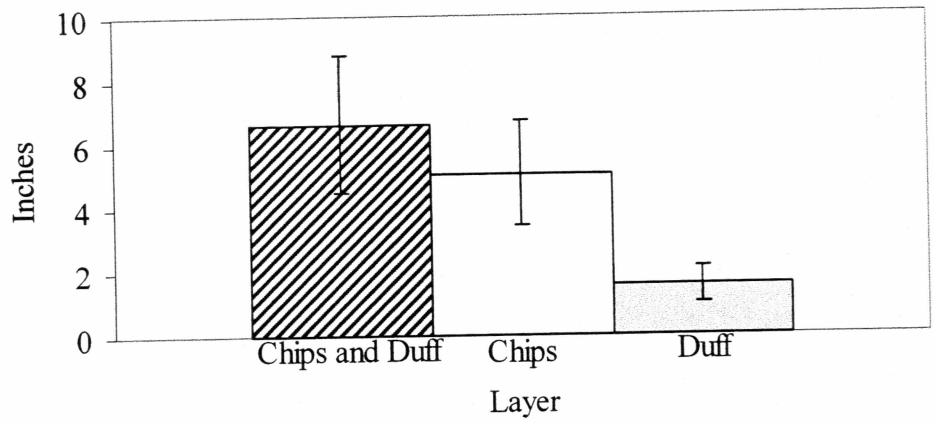

Figure 17. Mean of fuelbed depths after treatment, Masticate and Leave (ML) treatment (95% confidence interval, n=3).

This treatment was relatively expensive. Machine hours varied for different passes from 6.9 for the first pass to 3.4 for the third pass (Table 8). Costs ran from $2,700.00 to $4,795.50 per acre(Table 9) depending on the number of passes. Machine hours might be lower on sites that are less steep. Slopes as low as 10% proved to be an obstacle for the wheeled machinery used in this treatment. The operator worked uphill of the vegetation to avoid orienting the machine cross-slope on the first pass; this added to the machine hours provided in Table 8.

4.4 Shearblade and Leave Material (SL)

This treatment unit is the only one that did not address slash generated during the treatment. Slash remaining on site (Figure 18) adds two disadvantages to the treatment: 1) increased fuel load and 2) increased difficulty for wildfire suppression forces in accessing the area. The fuel loading estimate for this treatment unit is 690% of the original downed woody debris load (Table 6 and Appendix 2). This estimate is low because the operator inadvertently cleared portions of the PSPs when exiting the unit. The duff layer was reduced to 59% of its original depth (Table 6) this may be due to the drying out of mosses and/or compression of the duff layer during shearblading.

Hardwood regeneration appeared to be somewhat protected from browsing moose after the 2004-growing season due to the slash.

This treatment was the least expensive overall. It required only 0.6 machine hour per acre (Table 8) and cost $350.00 per acre (Table 9).

Figure 18. Shearblade and Leave (SL) treatment unit, 2004.

Topography was an operational issue with the shearblade, however. The operator had trouble maintaining the level of the shearblade when a sharp roll or "hummock" was encountered. Where these variations in topography were too sharp, the organic layer was either completely untouched by the shearblade or completely scraped away.

4.5 Shearblade, Windrow, and Burn Material (SB)

This treatment removed a large portion of the woody debris from the site, but not everything. Downed woody debris was increased to 542% of the original tons/acre on the site while duff was reduced to 69% of the original depth (Table 6). The downed woody debris left on site was 1-3 inches in diameter or in the 10-hr timelag fuel class (Figure 19 and Appendix 2) that is not as readily available for wildfire as the smaller diameter woody debris that was on site before treatment.

No regeneration data is available for the SB treatment unit because it did not have a full growing season before regeneration data were collected. Figure 19 shows that only parts of the site are scorched. At this time, it is unknown if this scorching will have a significant impact on the effectiveness of the treatment.

The cost of burning windrows was relatively low, 10.2 man hours and 3.4 machine hours per acre (Table 8). Unfortunately, dollar costs are unavailable for the burning of the windrows because burning was performed by Alaska Department of Natural Resources Division of Forestry personnel rather than on a contract basis.

4.6 Shearblade, Chunk, and Remove Material (SR)

Figure 20 shows what the windrowed material looked like before chunking with the tub grinder (Figure 8). No downed woody debris or duff measurements are available because the treatment was not completed until the fall of 2005; but, because all the material was removed from the site, there should be less material on site than there was before treatment.

Figure 19. Shearblade, Windrow, and Burn (SB) treatment unit, 2004.

Figure 20. Windrows at the Shearblade, Chunk, and Remove (SR) treatment unit, 2004, before chunking and removal.

No regeneration data is available for the SR treatment unit because it did not have a full growing season before regeneration data were collected.

The SR treatment has the added attraction of potentially using the material for roadfill or surfacing to offset costs. However, it proved to be time consuming and expensive relative to burning material. Chunking and spreading of the material on the Cache Creek road took 94 machine hours (Table 8) and cost $4,656/acre (Table 9). Because the effectiveness of the chunks as roadfill is still unknown, it is not possible to assess whether treatment costs were offset.

4.7 Drum-Crush and Burn Material (DB)

Downed woody debris and forest floor measurements were not made before or after this treatment because the treatment was added after snow covered the site and the broadcast burn is incomplete.

No regeneration data is available for the DB treatment unit because it did not have a full growing season before regeneration data were collected.

This treatment was not expensive relative to the other treatments; at 0.7 man hours per acre and it cost $480.00 per acre (Tables 8 and 9).

However, the DB treatment proved to be a nonviable option for fuels treatment. The crusher was supposed to cut stems into four-foot lengths, but it did not cut the larger stems. The broadcast burn was less successful than pile or windrow burning in the other treatments, because of less tightly packed fuels and possibly weather conditions.

Figure 21 shows stems that were not cut by the drum-crusher. The photo was taken after the attempted fall 2004 broadcast burn that did not carry into the center of the unit.

The day of the drum-crushing approximately 2.5 feet of wet snow covered the ground. This negatively impacted the success of the treatments. Factors that might have increased the effectiveness of this treatment are: using a larger dozer (a D7 was used), filling the "drum" with water to increase weight, and using ice grousers for traction on the dozer.

Figure 21. Drum-crush and Burn (DB) treatment, 2004 prior to burning. The burn was not completed in 2004.

4.8 Control (C)

The C treatment unit was visited in 2004. No measurements were taken because the site was not disturbed. This unit still looks similar to Figure 12. One potentially important advantage that the C treatment has is that the ground will not be subjected to increased insolation due to canopy removal. Graham and others (2004) noted that this radiation increase may dry surface fuel and lead to more intense surface fires.

4.9 Comparisons Among Treatments

By design, the results for each treatment unit look different. The study was exploratory, a beginning. Operational time frames resulted in incomplete data sets, hence, comparisons between treatments are made only with the limited data available.

Surface fire risk differs by treatment because of fuel arrangement and loading (Table 6). The SL treatment leaves all material on site and above ground; it has the highest amount of downed woody material present on any site (Appendix 2). The ML treatment has all material mulched and on the ground. The TB, SB, and DB treatments have or will have very little woody material on the ground. The SR treatment has virtually no woody material left on site and thus presents the least risk of surface fire.

For all treatment units except C, the possibility of crown fire has been eliminated for the present. Figure 22 shows the number of hardwood and spruce trees per acre for the seven treatment units in 2004. The TB treatment's widely spaced hardwood canopy will not support a crown fire; the other five treatments lack a canopy altogether.

The future of the treated stands is unclear. Hardwood regeneration was observed in treatment units that were completed by 2004. The visual observation that regeneration was less throughout the ML treatment prompted the ANOVA presented in Table 12 which showed no significant difference (p-value = .9468) between the regeneration on the three treatment units that were finished in time for the full 2004 growing season (SL, ML, and TB). Figure 23 shows the regeneration for the TB, SL, and ML treatments, and Figure 24 shows the same except that a ML treatment PSP with more regeneration than the others was taken out to show the effect this PSP had on the ML regeneration mean.

Table 12. Regeneration single factor ANOVA for Shearblade and Leave (SL), Thin, Pile, and Burn (TB), and Masticate and Leave (ML) treatments.

SUMMARY

Treatment Unit	Count	Sum	Average	Variance
Shearblade and leave	3	440	146.667	18308.3
Thin, pile, and burn	3	560	186.667	46308.3
Masticate and leave	3	630	210.000	102775.0

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	6155.56	2	3077.78	0.05516	0.94681	5.14325
Within Groups	334783	6	55797.20			
Total	340939	8				

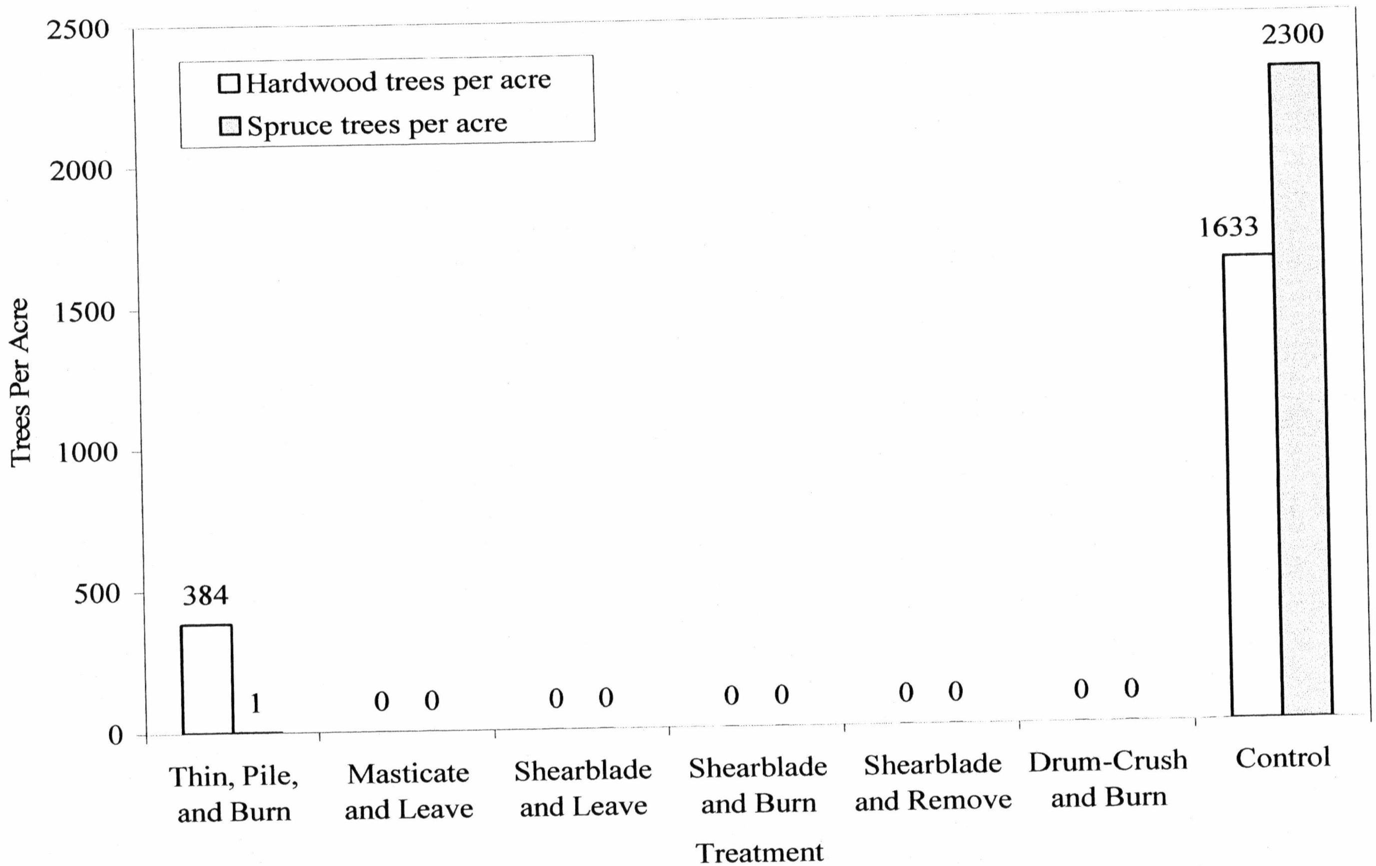

Figure 22. Trees per acre in 2004 after treatment. Thin, Pile, and Burn (TB) calculated from contract specifications. Control (C) from 2003 data.

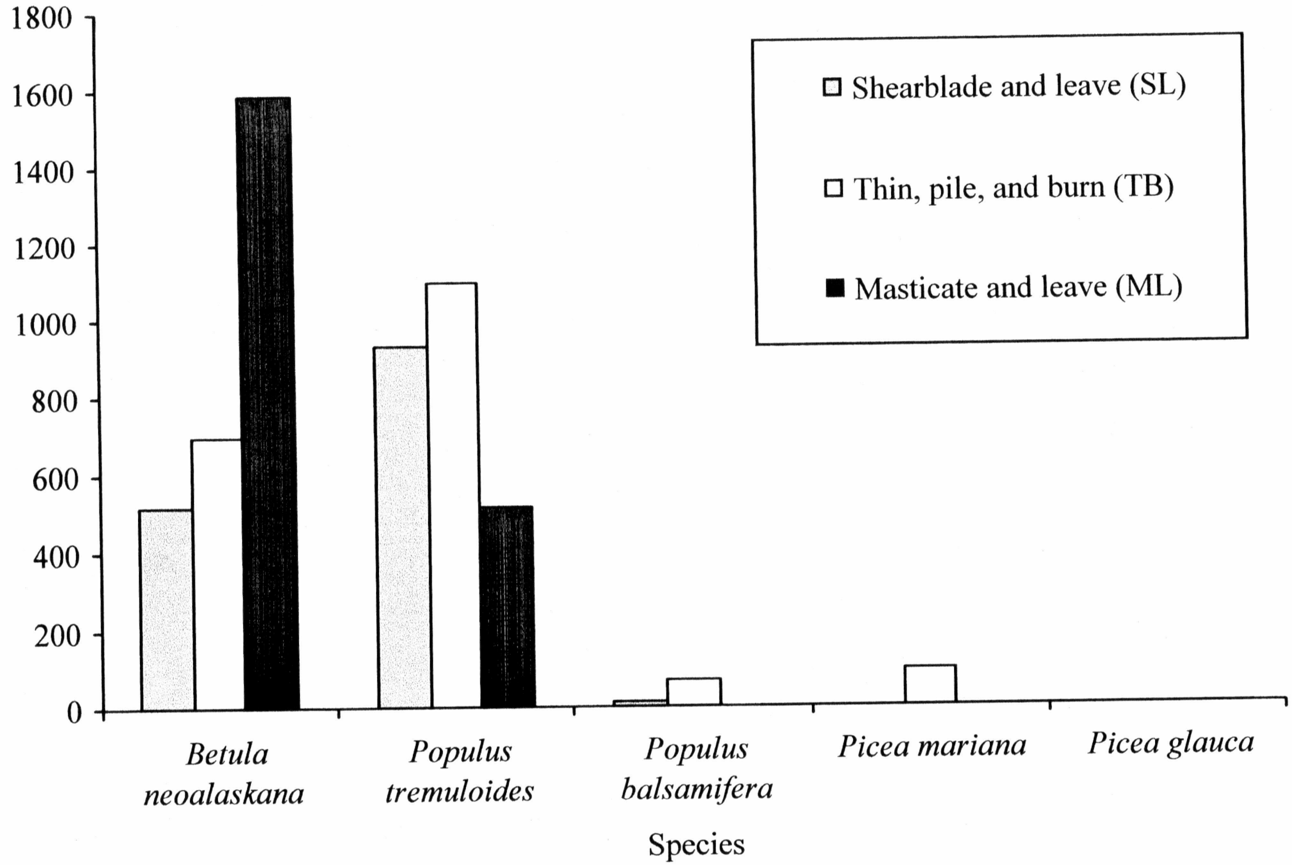

Figure 23. 2004 regeneration data, Cache Creek study area, trees per acre by treatment (n=3)

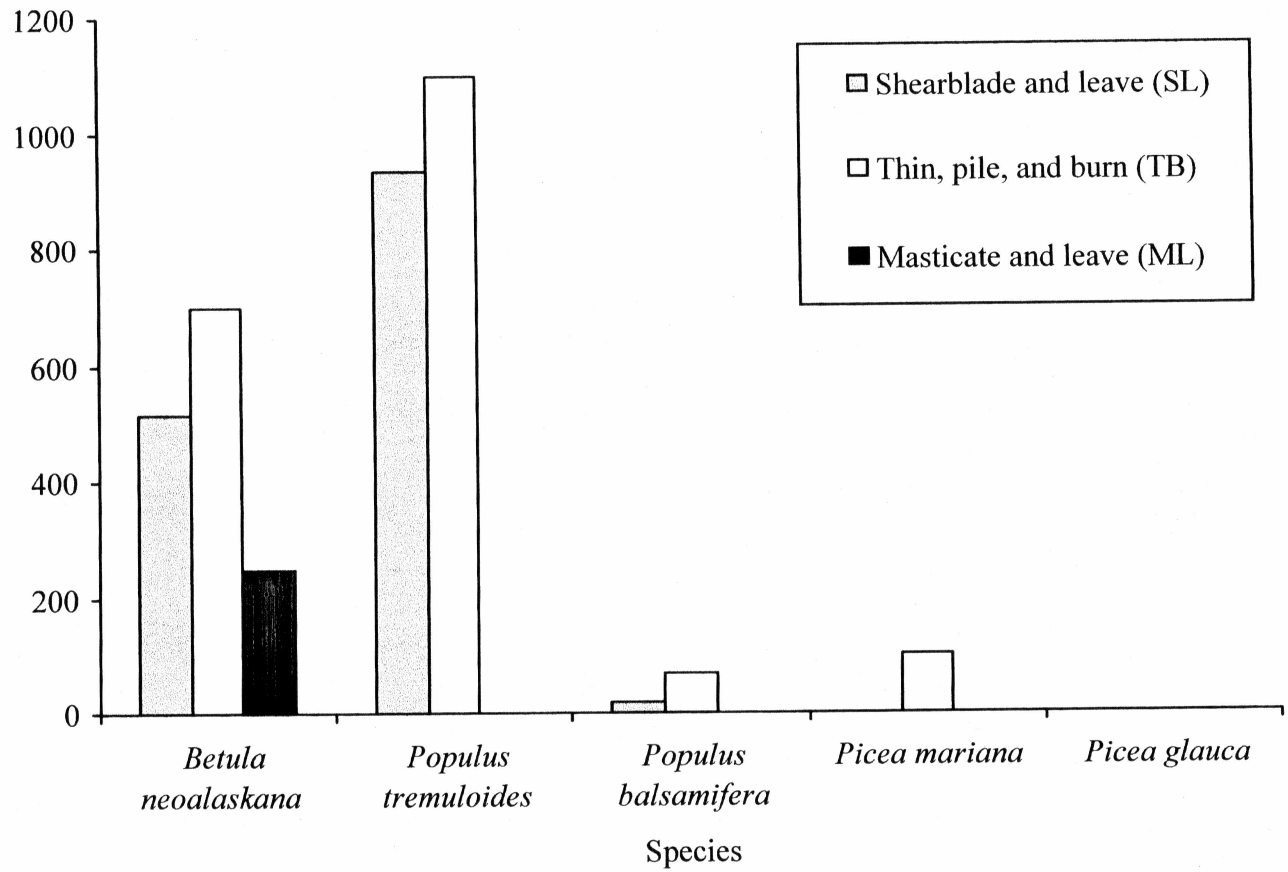

Figure 24. 2004 regeneration data, Cache Creek study area, trees per acre by treatment (n=3 except for Masticate and Leave [ML] where n=2 because the Permanent Sample Plot (PSP) with the most regeneration was excluded).

Cost values are presented in both man/machine hours and dollars per acre in Tables 8 and 9. These data attained from the Cache Creek study and interviews with agency personnel should be useful for planning forest fuels conversion/reduction treatments when combined with site information and current dollar costs for particular geographic areas. The treatment types and associated dollar costs are presented in Table 9 and vary widely due to management philosophies, agency constraints, and availability of equipment for particular locations. Many of the treatments presented in Table 9 were interagency projects spanning multiple years. Projects are listed under the name of the person providing the information, not necessarily the main agency funding the treatment.

Shearblading treatments are clearly the cheapest in terms of dollars and man-hours. The SL treatment took only 0.6 machine hours (Table 8) with costs ranging from $75 to $350 per acre (Table 9). The highest dollar cost treatment reported was the Denali Front Country treatment performed by the USDI National Park Service (Table 9). This treatment involved hand falling, slash material removal, transport, and distribution on a mining reclamation site near Healy, Alaska.[5] However, cost effectiveness can only be assessed relative to management objectives. Given the fuels conversion objective of the Cache Creek study area, shearblading is the most cost effective.

[5] Personal communication. September 29, 2004. Dan Warthin. USDI National Park Service, Denali National Park.

Chapter 5 Conclusions and Management Recommendations

The overall goal of this thesis was to test and assess stand-level fuels conversion treatments in interior Alaska. Through the literature review, installation of PSPs, and the collection of cost data both in dollars and man/machine hours insight was gained into the usefulness of the tested fuels conversion treatments.

Prior to this study, fuels treatment effectiveness studies in interior Alaska were limited to computer modeling exercises. The Cache Creek study area is now established as a site where different fuels conversion treatments can be observed and monitored for effectiveness. Also, water-repellent property and color changes were noted in soils underneath burned slash piles.

Agencies use a variety of treatments and incur a variety of different costs partially due to management style and organizational constraints (González-Cabán and McKetta 1986). The dollar and man/machine hour costs in Tables 8 and 9 can be used to quickly estimate costs of a proposed fuels treatment in conjunction with an estimate of the amount of material on site based on publications like Ottmar and Vihnanek's (2002) stereo photo series.

Visual observation and preliminary data indicate that hardwood regeneration is occurring on all treatment units within the Cache Creek study area after a single growing season. Results will become more definitive as time passes. Following Packee's (1990) recommendation of five to six years for spruce regeneration surveys, a regeneration survey in 2010 should provide an indication of the spruce component regenerating in the study area. At that time, an indication of how severe the impact of moose browsing on hardwood regeneration will be as compared to that described by Andrews (1998) and Cole and others (1999).

The nature of fuels conversion projects makes it difficult to state what treatment is the "best". The answer always depends on specific management objectives for a particular piece of the landscape. Given the objective of fuels conversion of a conifer stand to a hardwood stand at the smallest dollar-per-acre price, shearblading was the most cost effective (in both dollars and man/machine hours) at both the Cache Creek study area and at other sites carried out by various other agencies. If slash removal is part of the objective, burning windrows onsite is cheaper than chunking or removing material.

Creativity in designing fuels treatments is essential, because treatments are limited. Management objectives should take into account fire danger, cost, topography, aesthetics, soils, slash, access, and the general lack of information on the effectiveness of fuels treatments in the literature. Fuels treatment effectiveness should then be determined relative to management objectives.

I conclude with the following important unanswered questions for future research on fuels conversion:

- Can this study be replicated on similar sites?
- Will fuels conversion work on sites completely dominated by black spruce?
- Is aspen regenerating by seed more prolifically on burned compared to unburned areas?

- What are the implications of changes in soil color and water repellent properties after burning debris piles or windrows?
- Will there be significant differences in regeneration among treatments after 5 to 10 growing seasons?
- Are there a ways to offset costs of fuels treatments by creating markets for small diameter trees or resulting slash?
- In an actual fire, rather than a modeling exercise, how would different fuels treatments burn and what are the results under the same conditions?
- How would fuels conversion treatments burn during different stages of succession under the same environmental conditions and what would be the results?

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Appendices

Appendix 1. Fire cycle in the Boreal Forest by location and vegetation type.

Fire Cycle/Rotation (Years)	Location	Forest Type	Reference
43	Porcupine River Drainage, Alaska	Overall forest	Yarie 1981
113	Porcupine River Drainage, Alaska	White spruce	Yarie 1981
36	Porcupine River Drainage, Alaska	Black spruce	Yarie 1981
26	Porcupine River Drainage, Alaska	Hardwoods	Yarie 1981
130	Interior Alaska – NW Yukon	Open spruce-lichen forest	Viereck 1973 Barney 1971
100	Interior Alaska – NW Yukon	Closed spruce-birch or black spruce	Viereck 1973 Barney 1971
200+	Interior Alaska – NW Yukon	Floodplain white spruce	Viereck 1973 Barney 1971
120	Mackenzie, North West Territories	Open spruce near treeline	Johnson and Rowe 1975
100	Norman Wells, North West Territories	Black and white spruce	Rowe and others 1974
100/25	Fort Simpson, North West Territories	Open jack pine	Rowe and others 1974
200+	Mackenzie, North West Territories	Floodplain white spruce	Rowe and others 1974
49	NE British Columbia	Lodgepole pine	Heinselman 1981

Appendix 1. (continued)

Fire Cycle/Rotation (Years)	**Location**	**Forest Type**	**Reference**
103	NE British Columbia	Spruce	Heinselman 1981
103	West Alberta	Lodgepole pine -spruce	Van Wagner 1978 Heinselman 1981
50	Boundary Waters Canoe Area Wilderness, Minnesota	Jack pine-black spruce	Heinselman 1973 Heinselman 1981
80	Boundary Waters Canoe Area Wilderness, Minnesota	Aspen-birch-fir	Heinselman 1973 Heinselman 1981
180	Boundary Waters Canoe Area Wilderness, Minnesota	Red and white pine	Heinselman 1973 Heinselman 1981
175-300	Algonquin, Ontario	White pine-aspen	Cwynar 1978
136	Gouin Reservoir, Quebec	Overall forest	Lesieur and others 2002

Appendix 2. **Planar transect data summary by Permanent Sample Plot (PSP) for 2003 and 2004.**

			Tons/Acre						Inches		
Treat -ment	**Year**	**PSP**	**<.25**	**.25-1**	**1-3**	**>3 sound**	**>3 rotten**	**Sum wood**	**Mean duff**	**Mean litter /chip**	**Mean total Floor**
TB	2003	4	0.22	0.77	0.85	0.00	0.00	1.84	1.55	---	---
TB	2003	5	0.41	1.03	0.56	0.00	0.00	2.00	2.33	---	---
TB	2003	6	0.43	2.31	0.85	0.45	0.00	4.03	1.90	---	---
ML	2003	13	0.11	1.54	0.56	1.91	0.00	4.13	2.95	---	---
ML	2003	14	0.04	2.05	1.41	0.00	0.00	3.50	2.93	---	---
ML	2003	15	0.25	1.54	3.39	6.89	0.00	12.06	2.68	---	---
SL	2003	1	0.07	0.26	1.43	0.75	0.00	2.51	2.75	---	---
SL	2003	2	0.06	0.77	0.28	0.00	0.00	1.11	3.50	---	---
SL	2003	3	0.02	2.05	1.41	0.00	0.00	3.48	1.46	---	---
SB	2003	7	0.18	1.28	0.85	0.00	0.00	2.31	0.60	---	---
SB	2003	8	0.08	0.26	0.28	0.00	0.00	0.62	1.95	---	---
SB	2003	9	0.23	1.03	0.56	0.00	0.00	1.82	2.05	---	---
C	2003	16	0.10	0.00	0.28	0.00	0.00	0.38	3.00	---	---
C	2003	17	0.04	0.77	0.00	0.00	0.00	0.81	2.95	---	---
C	2003	18	0.16	1.03	0.56	0.00	0.00	1.75	3.19	---	---

Appendix 2. (continued)

			Tons/Acre						Inches		
Treat -ment	**Year**	**PSP**	**<.25**	**.25-1**	**1-3**	**>3 sound**	**>3 rotten**	**Sum wood**	**Mean duff**	**Mean litter /chip**	**Mean total Floor**
TB	2004	4	0.09	0.00	1.13	0.00	0.00	1.22	1.70	0.76	2.47
TB	2004	5	0.04	2.56	1.13	0.00	0.00	3.73	1.32	1.69	3.01
TB	2004	6	0.05	3.59	0.56	0.00	0.00	4.21	1.32	1.13	2.44
ML	2004	13a	0.00	0.00	0.00	0.00	0.00	0.00	1.80	6.21	8.01
ML	2004	13b	0.00	0.00	0.00	0.00	0.00	0.00	1.13	4.45	5.58
ML	2004	13c	0.00	0.00	0.00	0.00	0.00	0.00	1.35	3.63	4.98
ML	2004	13d	0.00	0.00	0.00	0.00	0.00	0.00	1.50	4.33	5.83
ML	2004	14a	0.00	0.00	0.00	0.00	0.00	0.00	0.85	1.95	2.80
ML	2004	14b	0.00	0.00	0.00	0.00	0.00	0.00	1.35	4.78	6.13
ML	2004	14c	0.00	0.00	0.00	0.00	0.00	0.00	1.13	3.53	4.65
ML	2004	14d	0.00	0.00	0.00	0.00	0.00	0.00	1.25	3.13	4.38
ML	2004	15a	0.00	0.00	0.00	0.00	0.00	0.00	0.63	3.40	4.03
ML	2004	15b	0.00	0.00	0.00	0.00	0.00	0.00	0.83	2.63	3.45
ML	2004	15c	0.00	0.00	0.00	0.00	0.00	0.00	1.08	4.38	5.45
ML	2004	15d	0.00	0.00	0.00	0.00	0.00	0.00	1.20	3.38	4.58
SL	2004	1	0.16	2.56	1.13	5.57	0.00	9.42	0.57	0.93	1.50
SL	2004	2	0.45	5.90	17.50	6.72	0.00	30.57	2.10	0.65	2.75
SL	2004	3	0.30	3.59	3.11	2.02	0.00	9.01	1.90	0.68	2.58
SB	2004	7	0.05	1.54	3.95	3.71	0.00	9.25	1.23	0.35	1.58
SB	2004	8	0.05	0.51	3.95	2.25	0.00	6.77	1.15	0.18	1.33
SB	2004	9	0.07	1.03	1.69	6.95	0.00	9.74	0.78	0.23	1.00

Appendix 3. 2003 soil organic horizon thickness and color from Permanent Sample Plots (PSPs) 1-18[1,2].

Treat-ment	PSP	Litter (in.)	Ferment-ation (in.)	Humus (in.)	Depth char-coal present	Depth of 1st color (in.)	Soil Color	Depth of 2nd color (in.)	Soil Color	Depth of 3rd color (in.)	Soil Color
TB	4	0.50	1.50	0.50	00.50	0+	2.5Y 5/4				
TB	5	1.00	1.00	0.50	00.25	0-12	2.5Y 5/2	12-13	10YR 4/6	13+	2.5Y 5/2
TB	6	0.50	1.50	0.50	00.50	0+	2.5Y 4/3				
ML	13	0.50	1.00	0.50	00.00	0-4	10YR 5/2	4+	10YR 6/4		
ML	14	0.50	2.00	0.50	30.00	0+	10YR 6/4				
ML	15	2.50	0.50	0.50	40.00	0-3	5YR 3/3	3+	2.5Y 5/3		
SL	1	0.10	0.50	0.40	0.00	0-4	10YR 3/4	4-28	2.5Y 5/4	28+	2.5Y 5/2
SL	2	2.00	1.00	0.50	01.00	0-3	7.5YR 4/6	3+	2.5Y 5/4		
SL	3	1.00	1.00	0.50	00.05	0+	2.5Y 5/4				
SB	7	0.50	1.00	0.50	00.50	0+	10YR 4/3				
SB	8	1.00	0.50	0.50	00.25	0-1	10YR 3/1	1+	10YR 5/2		
SB	9	0.50	1.00	0.50	00.50	0+	2.5Y 5/3				
SR	10	0.50	1.75	0.25	00.50	0-3	2.5Y 5/4	3+	10YR 4/3		
SR	11	1.50	0.75	0.25	02.75	0+	10YR 5/2				
SR	12	0.50	1.00	0.50	00.20	0-12	2.5Y 4/3	12+	2.5Y 6/4		
C	16	1.00	0.50	3.00	00.25	0+	2.5Y 5/4				
C	17	0.50	0.50	2.50	00.25	0-17	2.5Y 4/4	17+	2.5Y 4/3		
C	18	1.00	0.25	0.75	00.25	0-18	2.5Y 5/3	18-22	7.5YR 4/1	22+	2.5Y 5/4

[1]PSPs 19-21 were installed in the winter and thus do not have soil pit data.
[2]All pits were dug to 40 inches and all soils were observed to be silt-textured loess to that depth.